CLASSIFICATION CHANGED

ATI

FROM RESTRICTED TO UNCLASSIFIED

Insert Class Insert Class

85217

ON 27 Feb.1956 By authority of Classification cancelled in accordance with Executive Order 10501 issued 5 November 1953 Document Service Center Armed Services Tech. Info Agenc.

Month Day Year Specify Authority Being Used

This action was rendered by Arthur E. Creech OSP

Name in full Date

Document Service Center, ASTIA

SECURITY INFORMATION
RESTRICTED

CATI NO. 85 217

ANALYSIS AND EVALUATION OF GERMAN ATTAINMENTS AND RESEARCH IN THE LIQUID ROCKET ENGINE FIELD

VOLUME VIII

ROCKET ENGINE CONTROL AND SAFETY CIRCUITS

American Power Jet Company
Montclair, N. J.

March 1952

Published by
CENTRAL AIR DOCUMENTS OFFICE
(Army - Navy - Air Force)
U. B. Building
Dayton 2, Ohio

SECURITY INFORMATION
RESTRICTED

ABSTRACT

This report comprises the analysis of foreign liquid rocket research dealing with rocket engine controls and safety circuits. Leading examples of JATO, missile, and aircraft prime-mover rocket engines are analyzed to display the different control requirements and methods adopted to achieve the desired control and safety characteristics. The selection of examples permits a comparison of the control considerations when liquid oxygen is used and when nitric acid is used in anergole or hypergole propellant combinations. Whereever possible, the design details and operating experience are included.

The approach used in the analysis is to state the design data and specifications which were to be met, and present notes on the interrelation between the control and safety components and other design factors. Each analysis is completed by summaries and evaluations, including possible application to American practice.

The data and analysis presented in this volume supersede all earlier progress reports. A list of the leading references is appended. It is not exhaustive, but, rather, represents information deemed reliable and of further interest on specific points.

This volume is closely integrated with the other volumes of this series covering the APJ foreign liquid rocket analysis program. Pertinent portions of the 51-0-12 report series (Vol. I) are referenced to avoid duplication and to increase the over-all utility of the material presented.

ANALYSIS AND EVALUATION OF GERMAN ATTAINMENTS AND RESEARCH IN THE LIQUID ROCKET ENGINE FIELD

PREFACE

Volume VIII is one of a series of 14 volumes covering the compilation, resume', and analysis of German liquid rocket engines, procured from the American Power Jet Co. under Contracts No. W-33-038 ac-17485 and No. AF 33(038)-3636 with the Intelligence Department, AMC, Wright-Patterson Air Force Base, Dayton, Ohio.

The 14 volumes of the series are as follows:

ATI-85213

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

VOLUME VIII

ROCKET ENGINE CONTROL AND SAFETY CIRCUITS

INTRODUCTION

Rocket engine controls consist of the components required to assure the proper functioning of the major rocket-engine subassemblies. Although the interpretation of what elements are properly to be regarded as part of the "control system" varies according to the design practice and organization of various companies, it is here defined as including the following:

1. Lines and connections for conducting the propellants
2. Valves and other propellant-flow control devices
3. Actuating and sequencing mechanisms for controlling valves and initiating the operation of other subassemblies, such as the pump drive
4. Means for initiating combustion chamber operation
5. Safety and emergency shutdown devices

The functions of the rocket engine control and safety circuits are to assure the safe transfer of propellants from their tanks to the combustion chamber and to provide for ignition and sequencing, as well as shutdown in the event of failure.

Design Data

Design data constitute the procuring agency's specification for any given rocket engine and contain a maximum of information concerning the following:

1. Mission
   a. Function of the vehicle using the rocket
   b. Function of the rocket
   c. Installation of the rocket in the vehicle
   d. Expected flight attitude
   e. Expected ambient pressures and temperatures
   f. Over-all safety requirements
2. Thrust and impulse
3. Propellants to be used
4. Propellant feed system (pump or pressure)
5. Propellant ignition - single or repeat use
6. Weight and space limitations
7. Scale of utilization (experimental or production)
8. Acceptance test
9. Extent of compliance with conventional aircraft engineering standards
10. Delivery date

The design data required for a control system may contain all or part of the information listed above, elaborated to a greater or lesser degree. The state of the rocket art was such that the usual manner of providing the specification left considerable latitude to the discretion of the designer. Sometimes, however, special requirements peculiar to the installation exercised a strong influence on the type of control provided and made deviations out of the question, even at the expense of performance and safety. A case in point is the Peenemunde B-series JATO (discussed below), where the requirement for cross-coupling of every step of the operating sequence between the two JATO units mounted on the aircraft almost dictated an electrical control system interlocking each phase of the operation.

The detailed examples considered below for a representative JATO unit, missils, and aircraft prime mover will provide further elaboration on the design data provided.

Interrelation of Component Design Factors

Pump vs Pressure System

It is sometimes contended that the method of propellant supply imposes fundamental differences in the control system. However, extended and thorough analysis of foreign rocket system applications discloses that, while differences in control certainly exist between pump and pressure feed systems, they are relatively unimportant as compared with other mission requirements. Thus, for example, it is possible to design a pump system for an extremely simple application, e.g., constant thrust and single use. By contrast, a pressure-type system may be designed for variable thrust and repeated air borne starts. Several cases in point may be adduced.

1. Although the BMW 109-718 was a pump-fed system, it had extremely simple controls because (a) its mission required unthrottled application, (b) the nature of its propellants made the use of special ignition devices unnecessary and (c) it was mechanically geared to the BMW-003 turbojet and, hence central functions such as pump starting, etc., were automatically solved by the normal turbojet start and subsequent clutch operation.

2. Although no pressure-type, operational foreign liquid-rocket engine designed for throttlable use and repeated air-borne start was located, consideration may be given to an American unit, - the Reaction Motors power plant designed for the X-1. This pressure-fed rocket is designed to meet the requirements for intermittant air-borne starts and for the cutting in or out at will of any combination of its four thrust cylinders. Here the use of anergole propellants (oxygen and alcohol) plus the throttling requirement results in a comparatively complex control system.

An analysis of the foregoing examples discloses that the gross differences between the respective control systems arise not so much out of the method of propellant supply, but rather out of other requirements, such as propellant selection and throttling, which are correlated with the mission and installation of the power plant.

However, some comment may be made on the interrelations between the control and the propellant feed systems as divorced from other mission requirements.

Pump Systems

The analysis performed in ATI Report No. 51-0-12F (Vol. V) demonstrates that most foreign operational liquid-rocket engines having pump propellant feed employed steam-generater-driven turbines to power the pumps. Accordingly, the control system must make provision for starting the steam generator and assuring that the pumps come up to pressure before permitting the next stages of operation to take place. This is usually a more complex procedure than in the case of a pressure system, inasmuch as the following steps are required:

1. Steam-generator ignition must be initiated in one of the following ways:
   a. Auxiliary pressure system (A-4)
   b. Gravity start (109-509A-2)
   c. Electric motor (P 3390A)

This occasions the operation of on-off valves, propellant ignition, timing, switches, etc. Where a gravity starter or electric motor is used, additional controls are needed to cut them out after the start. In the case of a gravity starter, appropriate lines and check valves are also installed to replenish the starting supply.

2. Once the steam generator has been started, it is necessary to maintain its propellant supply. Controlwise, the auxiliary pressure type is the simplest, but it is also the heaviest. Both gravity and electric-motor start systems are fed by bypass lines from the pump; their operation must, of course be properly sequenced. After the proper pressure is reached, the remainder of the operating cycle is closely analagous to that in the pressure system.

The additional controls required for the above procedures are due to the fact that a steam generator is, in effect, a rocket motor adapted for the purpose of steam generation. For example, the steam generator system used on the A-4 has the greatest similarity in function and structure to the Walter 109-500 JATO unit, even to the sequence mechanisms, valves, and combustion chamber.

Pressure Systems

Six different types of operational foreign pressure systems were located and analyzed in APJ Report No. 51-0-12H (Vol. V). Here again, the dominant effect of the mission requirements is extraneous to the propellant supply system. Compare the simplicity of the 109-548 with the relative complexity of the B-series JATO. The 109-548 control merely required that a single electrical contact be closed, actuating a powder squib, and all following operations were completely automatic. On the other hand, the B-series development, culminating in the B-8a, had an elaborate system of electrical interconnections, level-sensing devices, and pressure and valve-position indicators. Yet both units had pressure feed systems; both were pressurized by compressed gas, and were not intended for intermittent operation during flight.

The following table presents a number of representative types of pressure systems together with a summary of their control and safety features.

In only one case is the control influenced by the specific type of pressurizing means employed. This is the differential piston, in which the flow conditions are strictly determined by the differential piston areas.[1/] The remaining systems using compressed gas may have widely varying control characteristics. More significant interrelations appear out of the problem of thrust control and propellant selection.

Rocket Motor Thrust Control

Rocket-motor thrust control is the subject of an entire APJ report (No. 51-0-12D, Vol. VII). Varying thrust programs for both pressure and pump-type systems, including JATOS, missiles, and aircraft prime movers using a variety of propellants, were analyzed. This report should be consulted for an extended analysis of the control interrelations arising as a consequence of the thrust control requirements.[2/]

1/ This has been demonstrated in APJ Report No. 51-0-12H (Vol. V).
2/ See especially Vol. V.

The requirement for rocket thrust control arises from two general types of conditions:

1. Acceleration and maneuvering requirements for guided flak missiles

2. Piloted aircraft applications

In the first application, fuel economy is regarded as relatively unimportant because of the short duration of operation. Also, the respective requirements for thrust and acceleration fit the polytropic expansion curve of the compressed gas fairly well.[3/] The control may, therefore, be relatively uncomplicated.

Piloted-aircraft applications, on the other hand, require a maximum conservation of fuel and, hence, the maintenance of the jet velocity at a high level. Moreover, throttle settings in piloted aircraft must provide a high degree of thrust-control flexibility, and the system must follow the various throttle settings closely and rapidly.

The requirements for securing a rapid response rate and for minimizing the deterioration of performance with throttling through a wide range give rise to arrangements of varying degrees of complexity. For example, the Walter 109-509 system resorted to staged controls to hold their design injector drops and, hence, to retain a maximum degree of injector performance in the throttled condition. Similarly, the main regulator valves for the 109-509 and the BMW P 3390A had performance characteristics which were dominated in large part by the requirement for rapid thrust control.

Propellant Selection

The principal influence of propellant selection on the control system is in the ignition characteristics of the propellant combination. Hypergole systems are self-igniting and require no special devices to initiate combustion; anergole systems must be provided with auxiliary igniters, as well as with a means for assuring accurate sequencing of ignition. Typical examples of the complicated control systems required for anergole injection are to be found in the B-8a and, especially, in the P 3390A.

Design Procedure

A careful consideration of foreign practice and experience discloses that there is no standard, mathematical, step-by-step procedure for the design of a control system. On the contrary, numerous alternative arrangements are available to experienced engineers. This is especially illustrated by the design sequence for the P 3390C (discussed in APJ Report No. 51-0-12D (Vol. VII) in which no less than 10 separate control patterns were designed, using a large variety of electrical and hydraulic procedures for accomplishing the control of a single basic system which did not change in major detail throughout the sequence. Similarly, even a relatively simple system such as the C-2 underwent at least six control system redesigns, the two leading ones of which are discussed below.

In deriving a control system, the various alternatives are successively considered and refined in the light of critique and test experience, until finally a satisfactory working arrangement is evolved. Generally, control systems tend to evolve from the complex to the simple.

3/ APJ Report No. 51-0-12D (Vol. VII).

Table 1

Control and Safety Features of Representative Pressure System Types

Type of Pressure System	Example	Control	Safety	Remarks
Basic	B-8a	Nonthrottlable. Regulated gas pressure. Controlled operational sequence. Pyrotechnic ignition	Built-in prefilght and operational check	Control circuit reasonable but safety circuit complex and cumbersome. Safety shutoff during operation
Free Piston	109-558	Regulated gas pressure. Throttled propellant flow by variable injector controlled by a Mach-number regulator. Hypergole ignition	Burst diaphragm in propellant lines holds propellants before operation	Control and safety relatively simple. No safety shutoff in operation
Inflatable Bag	109-513	Regulated gas pressure. Nonthrottlable. Pyrotechnic ignition	Rubber bag separation of oxygen pressurizing gas and fuel	Simple control and safety circuit. No safety shutoff in operation
Swinging Pipe	C-2	Regulated gas pressure. Non-throttlable. Hypergole ignition	Burst diaphragms. Safety valve in pressure regulator	Simple control and safety circuit. No safety shutoff in operation
Pipe Coil	109-548	Throttling by adiabatic gas expansion. Hypergole ignition	Burst diaphragms	Simple control and safety circuit. No safety shutoff in operation
Differential Piston	P 3374	Stable control dependent upon differential area, friction, chamber pressure, and propellant flow. Pressure cartridge start	Burst diaphragms	Self-controlling unit. Simple safety circuit. Automatic safety shutoff in operation. (Feed pressure dependent upon chamber pressure)

The design of a control system usually proceeds according to the following plan. An engineering conference is held to discuss and carefully consider the specifications, including:

1. Design data (given above)
2. Mission of control circuit
3. Corrosive properties of propellants
4. Availability of materials
5. Operating pressures
6. Operating temperatures
7. Availability of standard parts (e.g., tubing, tube connections, snap rings, seals, bearings etc.)
8. Prevailing company design standards
9. Development time available
10. Fabrication facilities
11. Testing facilities
12. Allowable cost

Numerous approaches to the problem are set forth, and the best proposal or proposals are roughly sketched out. The layout designers then work these sketches into basic schematic control and safety diagrams. These are reconsidered in the light of all the specifications; appropriate changes are made, and the final system is approved. The general functioning of each control and safety component is set, and the proper sequencing within the assembly is determined.

After the control system has been decided upon, an inboard profile layout is drawn to orient the various subassemblies within the space and weight limitations of the engine. The approximate hydraulic-line lengths are determined from this layout, and the various line sizes calculated according to the allowable pressure drops, due regard being given to weight and space requirements as well as to standard available sizes.

Individual components, or subassemblies, are assigned to various design engineers and the specific parts worked out. Layouts of each part are drawn, checked and changed until approved. Finally, detail drawings of each part within an assembly are made and approved.

The parts are then fabricated, checked, and assembled, and each assembly tested for its individual function, operational reliability, and general safety. Subassemblies may be grouped together and checked for sequencing and reliability. The electrical controls are schematically assembled on a test board, with the necessary relays, switches, wires, connections, etc., and realigned until the setup performs its proper function in exactly the correct sequence. Final wiring diagrams are drawn, and a mock-up of the entire rocket engine assembly made, to determine the final location of all the parts and to group the wires into cables for ease of assembly.

The actual controls may be assembled in the working mock-up and the entire arrangements checked for operation as a unit. If everything works according to the original schedule (some minor modifications may be indicated in the light of fabrication and assembly difficulties), final assembly drawings and installation instructions are completed and a prototype unit built and tested.

Revisions, with appropriate drawings and fabrication changes, will undoubtedly be required as a result of testing experience. When at last the engine meets all the specifications, it is submitted for acceptance testing and an approval check is made of the control and safety circuits, as well as of each individual component. If all requirements are satisfactorily met, the system is accepted and put into operation.

Since the final test of any rocket engine is the reliable and safe fulfillment of the original mission, only actual experience can finally determine the degree to which the engine fulfills its mission. After a small number of units have been built and used for the intended purpose, some modifications may have to be made before it is ready for large-scale, mass production.

Metallurgical Requirements

Metallurgical requirements of control systems vary with the function of the control-system subassembly. Thus, for example, the electrical subassemblies must satisfy the normal metallurgical requirements according to aircraft and electrical standards; hydraulic and pneumatic controls must conform to the characteristics of the working fluid. This is most apparent in the design of lines and valves.

Metallurgical requirements are discussed in detail for all relevant parts in the following sections of this report, covering the B-series (oxygen-alcohol), and the C-2 (mixed acids and Visol), as well as the P 3390A (nitric acid, methyl alcohol, Tonka, and water). In addition, a tabular summary is provided below in the section "Summary and Conclusions."

PEENEMUNDE B-SERIES JATOS

The major changes made in the B-series control systems were in the degree of complexity of their checking and safety mechanisms. The B-7 and B-8, intended as test and prototype units, respectively, had moderately complex controls. But the B-8a, intended for mass production, seemed to elicit a highly conservative attitude on the part of the designers, who took pains to provide elaborately against every possible contingency. As a result, the B-8a was excessively heavy and expensive, and overburdened with maintenance requirements. Furthermore, the safety circuit itself became a source of difficulty and introduced a further hazard of failure. This development was attributed in part to Peenemunde's initial inexperience with military operational conditions.

When Schmidding was to plan the mass production of an alternate JATO, there appears to have been a serious reconsideration of the control problem, with the result that the entire control system was drastically simplified.

The wide range of alternatives available to a designer from a single set of design requirements is displayed in the following analysis of the operational Peenemunde B-series JATOS.

Design Data

Mission

Function of vehicle using rocket - German medium bomber.

Function of rocket - Droppable and recoverable take-off assist.

Installation - Two rocket engines per aircraft, mounted under the wing. The Air Ministry required that both must be stopped simultaneously, although it should be possible to drop and parachute them down independently.

Expected flight attitude - Approximately horizontal.

Expected ambient pressures and temperatures - Rockets were to be dropped at fairly low altitudes; hence, ambient-pressure effects were negligible and only ground temperatures were to be taken into account. The range of ground temperatures was never stated explicitly.

Safety requirements - In addition to normal safety requirements providing for the automatic shutdown of the system in the event of failure, the operational conditions set forth above necessitated the following precautions:

1. Shutdown of one engine must automatically cut off the other one even if it is in good operating condition.

2. Each step in the starting sequence of one system must be timed to occur after the preceding step has operated satisfactorily in both systems.

The Air Ministry also made the following demands:

1. No combustion-gas-pressurized lines or controls, because of the probability of burnout in the presence of oxygen vapor

2. Separate fuel and liquid-oxygen tank vents, to avoid premixing of propellants

3. High-pressure gas filter, to protect valves, etc. from dirt and contamination

4. Exclusion of all liquid-oxygen gas-pneumatic actuators and controls, because of low-temperature problems

5. Two pyrotechnic igniters, to insure ignition if one fails

6. Fuel feed to be delayed until liquid-oxygen flow is assured and igniters are burning

7. Combustion must be cut out before fuel lines and cooling jacket are completely empty

8. The tanks must be vented after combustion cutoff

Thrust - 2200 lb

Duration - 30 sec for all but the B-7, which had 32 sec

Propellants - Alcohol and liquid oxygen

Propellant Feed System - Pressure

Propellant Ignition - Pyrotechnic (single use per flight)

Weight and Space Limitations - Not explicitly stated. A wide range of weights was encountered. Volume and frontal area were relatively unimportant since the B-series JATOS were for external installation and were to be dropped at relatively low speeds where drag was negligible.

Scale of Utilization - B-7 Test units only
B-8 Prototype for B-8a
B-8a Intended for production
G-1 Intended for production

Engineering Standards - No written specifications were located, but conventional aircraft engineering standards appear to have been observed throughout, with deviations as dictated by system requirements.

Interrelation of Component Design Factors

Influence of Propellant Selection

An ignition system was required because liquid oxygen and alcohol make an anergole combination. Simple pyrotechnic igniters sufficed, however, since the JATO was used only once before being dropped and rechecked.

In order to assure the smooth starting of liquid-oxygen combustion chambers, the liquid oxygen must be timed to enter the chamber before the alcohol.

The sensitivity of liquid oxygen to hydrocarbon contaminants precluded the use of greases or other lubricants in the fittings, valves, etc. Moreover, the extremely low temperature of liquid oxygen would freeze the lubricants solid. Consequently, the liquid-oxygen valving system, discussed below, was very simple compared with the pneumatically operated valves for the fuel.

No control problems were encountered as a result of the use of alcohol.

Propellant Feed System

The method of propellant feed in the B-series JATOS was of the basic-pressure type, using compressed nitrogen as the pressurizing medium. The availability of a ready source of high-pressure gas made the use of pneumatic controls a natural choice.

The simple operations required to secure propellant flow also simplified the procedure for system sequencing and control. This may be contrasted with the relative complexity of the pump-type control circuit discussed below in connection with the P 3390A. One requirement, however, was the use of a pressure regulator between the nitrogen bottle and the tanks to insure constant tank pressure; hence, the maintenance of propellant flow, and, therefore, constant thrust.

Installation

The installation of the JATO on the piloted aircraft made it necessary to provide appropriate cockpit controls for starting, stopping, and jettisoning, with corresponding signal lights. On the other hand, the aircraft installation made it possible to dispense with the use of separate batteries for the solenoid controls, since the unit could be plugged into the aircraft electrical circuit.

Metallurgical Requirements

The major limitation on materials selection for the control systems of the B-series JATOS stemmed from the use of liquid oxygen. Metals and other materials which become brittle at extremely low temperature were excluded. Thus, parts that were in contact with the oxygen could not be made of iron or carbon steel. Aluminum and brass, however, are not seriously affected by liquid oxygen and were generally used for valves, lines, and fittings.

The soft materials used for seals and valve seats presented a more difficult problem, since practically all suitable soft materials become hard in liquid oxygen and may be damaged during operation. Metal to metal valve seats were acceptable, but great care had to be taken in manufacture and handling if an absolute seal was to be maintained.

The use of alcohol as the fuel presented no unusual difficulties from the standpoint of materials selection; likewise, the mission, thrust and duration. Standard aircraft tubing, fittings, and seals were acceptable, and aluminum alloys could be used without detriment.

Conventional, aircraft-quality electrical cables, connectors, relays, and contacts were suitable for the control and safety circuits, although the contact points on the relays were occasionally troublesome. The special alloys usually required for continuous-duty relay contact points were scarce in Germany, and steel substitutes had to be made. If these were overloaded, the points became pitted and the relays stuck. This upset the sequencing and at times resulted in failure of the rocket engine.

Design Sequence and Operating Characteristics

The first of the operational Peenemunde B-series JATOS was the B-7. This section retraces the steps in the design sequence from the B-7 test unit to the B-8a and G-1 production models, and analyzes the performance and operating characteristics, including start, run, and stop for each of the four JATOS, as well as the control and safety components and their arrangement within the nacelle of the JATO. Schematic control drawings, wiring diagrams and inboard profile assemblies are included where available. In conclusion, a summary comparison of the main control features, the JATO characteristics, and the safety features are presented.

B-7 (See Figs. 1 and 2)

Component Arrangement

The arrangement of the B-7 components is shown in the schematic inboard profile. (See Fig. 2.) The spherical, insulated, liquid-oxygen tank is in the nose of the JATO, immediately behind the parachute and partially nested in the center of the annular-shaped alcohol tank. The nitrogen bottles and the pressure regulator are mounted in the center space of the alcohol tank.

While this arrangement certainly conserves longitudinal space, it imposes a considerable weight penalty on the system. This is evidenced by comparison with the B-8 design, in which spherical propellant tanks are used for both propellants.

The other control components are mounted in the available spaces according to their functions; e.g., the tank pressurizing valves and level indicators are attached on or near their respective tanks, and the fuel cutoff valve and liquid-oxygen check valve are in the space between the combustion chamber and outer shell.

Operation (See Fig. 1)

The nitrogen battery is charged through valve (5) (with hand valve (6) closed) until the high-pressure gage (21) indicates the proper pressure. (Account must be taken of the expected differences, if any, between the filling temperature and the ambient operating temperature.) The alcohol tank is filled through a valve (not shown) to a level which permits adequate expansion of the fuel, because of an increase in temperature that does not unduly strain or rupture the tank and lines. By gravity, the alcohol also fills the line and the combustion-chamber cooling jacket up to the cutoff valve (14). The liquid-oxygen tank is filled last because of the high evaporation rate of liquid oxygen with relatively poor (glass wool) insulation. If full impulse is to be obtained, the unit has to be used within 15 min after filling.

The operational use of the B-7 requires the utilization of two JATOS electrically interconnected on the aircraft, and both must be in perfect working order before either can be started. Hand valve (6) is first opened to arm the system. High-pressure nitrogen flows through the filter (19), is reduced in pressure by the pressure regulator (7), and stopped by the normally closed pneumatic valves (8 and 9) and by the solenoid-operated, normally closed pilot valves (10 and 11). When take-off thrust is desired, the pilot closes the "start" switch, which energizes and opens valve (10). Nitrogen flows through this valve to the pneumatic valve (8), which opens and allows the nitrogen to pressurize the liquid oxygen. A special outlet fitting (24) diffuses the incoming nitrogen and prevents undue absorption of the gas by the liquid oxygen.

The liquid oxygen is forced from its tank (2) through the filter (18), opens the check valve (12) and, finally, flows through the ball check-valve injector (22) into the combustion chamber (4). As soon as the liquid-oxygen pressure beyond valve (12) reaches 7 to 10 psi, and before check valve (22) opens, the pressure switch (16) is activated. This causes the electrical circuit to open valve (11) and start the igniter (17). The nitrogen pressure from valve (11) opens valve (9) and allows the regulated gas to pressurize the fuel tank. Valve (14) is opened and permits the alcohol to enter the chamber slightly later than the liquid oxygen. Ignition takes place and thrust is initiated.

The engine runs until the alcohol is expended to the level that activates the switch (13). This de-energizes valves (10 and 11), which close and, in turn, permit valves (8, 9, and 14) to be closed by spring force and fluid pressure against the inlet faces of their poppets. The liquid oxygen continues to flow until the pressure drops below that required to keep check valves (12 and 22) open.

In the event that the liquid oxygen is depleted first, switch (16) drops out and initiates the above shutdown procedure. The pilot may also cut the engines off by opening the main electrical switch, but he cannot restart the rockets because the powder igniter is good for one use only and must be replaced before re-use.

B-8 (See Figs. 3 and 4)

Component Arrangement

The arrangement of the B-8 components is shown schematically on Fig. 4. Since the B-8 was the prototype of the production version, RI-101b, the arrangement was in a constant state of flux. One or more assemblies similar to Fig. 4 were built, but no evidence was located to substantiate the construction of alternate designs.

As in the B-7, the control components are again located as close to their functional counterparts as space permits. The design arrangement disposes of the annular alcohol tank and introduces a novelty in the mounting of the rocket motor below the tanks. As carried out in this design, however, the new motor arrangement shows little merit, since the unit is actually longer than the others and the additional structure and protection needed for the motor mount result in a weight penalty.

Operation (See Fig. 3)

Upon completion of tanking and mounting of the two JATOS, the units are armed by opening the high-pressure hand valve (2) and closing the main electric circuit switch. The nitrogen flows from the tanks (1) through the hand valve (2) and is reduced by the regulator (3). The burst valve (4) and the pilot valve (5) prevent the gas from going further. When thrust is desired, the pilot presses the start button and both units either start simultaneously or not at all.

The start button closes the electrical circuit, which causes the solenoid pilot valve (5) to open and allow the nitrogen to burst the membrane assembly (4). The regulated gas then flows through fitting (6) into the alcohol tank and also through the normally vented, 3-way, ball check valve (7). The ball closes the vent and the gas flows over the baffle plate (8) into the liquid-oxygen tank. The fuel is forced through the outlet pipe to the combustion-chamber cooling jacket and is stopped by the cutoff valve (10). Liquid oxygen is simultaneously forced through its outlet pipe and activates the pressure switch (11) at approximately 7 psi before it flows through the injector (9) into the chamber.

Activation of switch (11) energizes relay (12) and causes valve (14) to open. This permits nitrogen to flow from the main-tank pressurizing line, through valve (14), and open valve (10). The igniters (not shown) are started when switch (11) is closed; hence, the propellants ignite when they enter the chamber.

Operation continues for about 30 sec until the alcohol-level indicator (13) cuts out relay (12) and, hence, valves (14). If the liquid oxygen runs out first, switch (11) opens and produces the same results. From his position the pilot may also open switch (12), but he cannot restart the rocket since the powder igniters must be replaced after each use.

Any one of the above three shutoff operations reverses the position of valves (14), and vents the fuel cutoff valve (10), which then closes. Simultaneously, compressed gas is forced between the diaphragms of the vent valve (15), and the fuel tank and compressed nitrogen bottles are vented to the atmosphere. The liquid-oxygen tank vents through the injector and chamber, and this provides an oxygen-rich cutoff, which is relatively smooth and free from afterburning.

Vent Valve

A detailed drawing of the liquid-oxygen-tank vent valve of the B-8 is shown in Fig. 11. It is a 3-way, T-shaped valve, attached directly to the tank by its middle leg. The pressurized-gas-entrance port is normally closed, so that the tank is vented to the atmosphere. When the unit is started, the nitrogen gas forces the ball against the vent port and pressurizes the tank. As soon as the gas stops flowing, the ball automatically returns to its normal position and the tank is again vented. Since the ball is self-centering, adequate sealing is assured, and no jamming or leakage occurred during a large number of actual tests.

Construction of the valve is extremely simple. The main housing (1) is an aluminum-alloy casting, internally machined for the valve seat and outlet-fitting threads (2), and machined on the outside for the inlet-fitting threads and tank-attachment threads. Most of the inner cavity is left as cast. The outlet fitting is screwed into the main body and the joint is sealed by a gasket.

The hard-rubber ball (4) is held against the seat in the main housing by the force of tension spring (5). One end of this spring is looped over a cast-in cross bar (10) in the inlet fitting; the other end is fastened to the ball by a special eyebolt (7) and nut (8), which is locked by a special tab washer (9). Leakage of gas past the eyebolt is prevented by a soft-rubber gasket (6) between a shoulder on the bolt and the bottom of the bored hole in the ball.

Such a check valve is extremely easy to fabricate and positive in its operation. The required opening force may be adjusted by changing the design of the spring and no pressure drop other than that caused by the unevenness of the interior and the elbow losses exists, once the vent port is closed.

In designing the production version of the B-series JATOS, the Schmidding Company later used this valve for the alcohol tank.

B-8a (R1-101b) (See Figs. 5-8)

Component Arrangement

The B-8a rocket engine consists of three main parts: housing, propulsion unit, and parachute. The housing is made of light sheet-metal; a steel pipe frame is connected to it for suspension on the airplane. The propulsion unit is installed in the housing and secured by means of tightening bolts, clips, screws, and other fasteners. It consists of the following five main parts: compressed gas assembly, tanks and feeding system, combustion chamber assembly, electrical installations, and measuring devices. The parachute is packed on a disk of sheet metal which is joined to the nose by means of 4 quick-disconnect fasteners.

Figures 6 and 7 show the top and side views, respectively, of the B-8a (RI-101b) JATO assembly. The extreme compactness of all major components is displayed, due regard being given to accessibility of parts. All controls are mounted on their functional complement or attached to the structure of the JATO itself, and may readily be reached through doors or removable hatches.

It is of interest to note the use of several small, high-pressure bottles mounted on the periphery of the thrust mount bracket. While this results in a weight increase over the use of a single, spherical gas container, it provides a more compact over-all unit and permits the use of standardized gas tanks. The loops and bends in all pipe lines and the single-point suspension of the combustion chamber, coupled with a slide mount on the motor cylinder just forward of the nozzle, provide adequately for the expansion factor.

There are two other points of interest. First, numerous small tubes converge at manifold coupling (22, Fig. 5) behind the liquid-oxygen tank, as shown in Fig. 6. This arrangement permits convenient checking of the pressures at various points prior to operation. Second, the use of an electrical junction box (23, Fig. 5) through which all electrical lines are routed. The junction box makes possible the safety and preflight check of the electrical control box (Fig. 7) without undue duplication of electrical wiring. It should be noted, however, that, despite this arrangement, approximately 115 ft of electrical wire are used in each JATO. The quick-disconnect electrical plug located near the front mount bracket (Fig. 7) is of conventional design, with the plug itself secured by cable to the JATO mount brace. This plug was standard for German JATOS and is the same as that used by Walter. (109-500/501/502 series).

Operation (See Fig. 5)

Operation is begun by filling the tanks. Tank (12) is filled with liquid oxygen, tank (16) with fuel, and the high-pressure tanks (3) with compressed nitrogen. Vent valve (18) permits automatic filling of the combustion-chamber cooling jacket while the fuel tank is being filled. To insure alcohol flow as soon as the circuit is energized, the air in the jacket and in the lines between the tank and motor is vented into the fuel tank through valve (18). When the fuel begins to feed, the pressure entering the fuel tank closes vent valve (18) and prevents the nitrogen from flowing into the cooling jacket. Any vapor which may form in the oxygen feed line is stopped at check valve (15), from which it must bubble back and be vented in the normal manner through valve (8). It is probable that a small amount of gaseous oxygen is injected into the system at the start, followed almost immediately by liquid; but the short line length prevents any adverse effect on the timing.

Two igniters (20) are installed in the combustion chamber (19). The duplication insures ignition in case of the accidental failure of one of the igniters and causes a wide and reliable ignition flame.

Normal operation of the unit requires that the alcohol-flow indicator (17) be actuated. During the start, however, the indicator must be by-passed, or starting is precluded. Accordingly, pressure switch (11) is inserted in the system in parallel (electrically) with the flow indicator (17), and the circuit may operate after a slight delay when feed pressure in tank (16) is reached. The delay is achieved by the pneumatic damper (10), which holds switch (11) closed until fuel flow is established and the alcohol-flow indicator is in operation. The pressure switch is then cut out of the circuit.

The high-pressure gas fill valve (2) is closed and the main on-off valve (4) opened. When the pilot closes the main switch, electrically operated valve (6) opens and the igniters are simultaneously energized. The high-pressure gas flows from the tanks (3), through valve (4), gas filter (5), and valve (6), to the pressure regulator (7). The gas pressure between valve (6) and regulator (7) closes the liquid-oxygen-tank vent valve (8). (Before start, the oxygen tank must be continuously vented through valve (8), since the oxygen is constantly evaporating.) Gas flows from the pressure regulator (7) at reduced pressure, through the diffuser (13), into the oxygen tank (12), and forces the oxygen through the feed line and the check valve (15) into the combustion chamber (19).

The pressurized gas is stopped by the four-way solenoid valve (9). (The mechanical design and operation of this valve are covered in detail below.) In the position shown the four-way valve vents the fuel tank and holds the main fuel cutoff valve (25) shut. The delay between the pressurization of the tank and the opening of valve (25) produces the desired lag in alcohol supply. In the normal position, valve (25) is held shut by a small spring which resists any gravity head of the fuel. The four-way valve (9) can be actuated only when both igniters (20) and the pressure switches (21) in both JATOS are energized. This procedure insures simultaneous starts.

Valve (9) is now actuated, pressurizing the fuel tank and simultaneously venting valve (25). Alcohol enters the injector and the motor starts. The system is now in full operation.

The propellant-tank volumes are so calculated that the fuel tank empties first. Allowance is made for the evaporation of approximately 15 gal of oxygen; but if this amount is exceeded, level indicator (14) holds the circuit open and start cannot be made.

When the alcohol tank is empty, the fuel-flow indicator (17) breaks the circuit and de-energizes valves (6 and 9), which return to their initial positions. The combustion chamber is thereby shut-off and the action of valve (9) again vents the fuel tank. As in the B-8, cutoff in the B-8a is oxygen-rich and relatively smooth and free from afterburning.

Safety Precautions (See Figs. 5 and 8)

The B-8a is provided with a well-developed series of automatic safety devices which check every step of the operation and prevent the next subassembly from operating until all prerequisites have been satisfied. The operational checks summarized below are transmitted through pressure-actuated switches and contacts to the electrical control box (23).

Safety Component	Function
High-pressure gage (24)	Prevents engine start if nitrogen pressure is below requirement.
Hand-operated, high-pressure, on-off, nitrogen valve with contact switch (4)	Must be fully opened for circuit to permit engine start.
Liquid-oxygen-tank fill-gage switch (14)	Remains open and prevents engine start if liquid-oxygen level is below permissible minimum.
Pressure switch (21)	Must be closed before the alcohol valve (25) is opened. Insures that the oxygen will lead the alcohol into the combustion chamber.
Cooling-jacket vent valve (18)	Prevents air from entering the chamber by permitting the cooling jacket to be filled with alcohol under gravity head.
Pressure manifold (22)	Contains leads to all major components and facilitates the recording of test data.

Figure 8 is an electrical wiring diagram. It shows the relationship among the circuit elements described, the interconnection of the two units as installed, and the ground checking circuit installed.

Pilot's Operating Procedure

The operating steps in the starting procedure of the B-8a are covered above in detail. As far as the pilot's control is concerned, however, the following is pertinent. Assuming that both JATOS have been installed, the pilot pushes a main switch, which provides current to the system. He then pushes the engine start button. If both engines start, a signal light is illuminated on his control panel; he should also feel the accelerating thrust.

Once the engines have begun to operate, they continue automatically and the pilot has no control over them except that he may at will open his main swtich and cut out both JATOS. In the event of system failure the safety circuits operate, shutting down the rockets and extinguishing the control panel lights.

It was apparently intended that the JATOS be dropped separately, since individual controls and jettison-indicating lights are provided. The lights go on at the time of release and may be put out by the pilot by opening the main switch.

Solenoid-Operated, Four-Way Control Valve (See Fig. 12)

The B-8a employs a solenoid, 4-way control valve for the purpose of venting the fuel tank and simultaneously pressurizing the fuel cutoff valve. When energized, the valve position is reversed, so that the fuel cutoff valve is vented through one port and the fuel tank is pressurized through the other. Figure 5 shows the schematic relationship of this valve (9) to the B-8a assembly.

Construction

The valve consists of three main parts (Fig. 12): the solenoid (1), the main body (2), and the movable valve poppet (3). The solenoid is essentially conventional in design and is composed of wire (4) wound around an iron core (5). An electrical connection (6) permits the attachment of the control wires.

The main body (2) is an intricately drilled, bored, and tapped aluminum casting. The main inlet port (7) is connected to the central annular space (8) by two drilled holes, one of which is sealed by a cap (9). The upper outlet (10) is connected to the fuel cutoff valve and the lower outlet (11) is connected to the fuel tank. Both the alcohol main valve and the tank are consecutively vented through the common vent port (12) by means of connecting, drilled holes which are capped by plugs (13 and 14). The valve is mounted to the JATO framework through holes (15).

Two identical, steel, spanner-type, cylindrical valve seats (16) are screwed into the central cavity (8). AN 902-type gaskets (17) prevent leakage through the threads, but no means is provided for locking the inserts in place.

Two idenitcal, steel, spanner-type inserts (18) are screwed into the housing, concentric with inserts (16). Leakage through the threads is prevented by synthetic rubber washers (19). These are retained in position by two other special steel spanner nuts (21), screwed into the first nuts (18). Internal guides (34) are provided on the two nuts (21) for the poppet assembly (3). No special provision is made for locking either nuts (18) or (21), other than the friction of the washers (19) or the valve seats (20).

The bottom of the valve assembly is sealed by means of an internal hex nut (22) screwed into the body against a soft gasket. Lockwire prevents the nut from loosening. The top of the valve assembly is capped by the solenoid (1). A special collar (24) is screwed on the body of the solenoid and is held to the valve body by a union type, spanner nut (23). Leakage through the threads of the spanner nut is prevented by another AN 902-type gasket.

The poppet assembly (3) consists of the main hollow stem (25), the hollow sleeve (26), a spacer ring (27), two synthetic-rubber washers (28), a nut (29), an adapter fitting (30), and the movable solenoid core (31). The adapter (30) is riveted to the core (31) by the rivet (32) and screwed into the top of the main valve stem (25). The two soft valve seats (28) are positioned against a shoulder on the main valve stem by the spacer (27) and held in place by the hollow sleeve (26). The sleeve is held tight by the hex nut (29).

The valve assembly contains four sealing surfaces. In the two outer ones the poppet moves and the soft seats (20) remain stationary. The reverse is true for the two inner ones: the soft seats (28) move with the poppet and the seating surfaces (16) remain stationary. The valve is so designed that one inner and the opposite outer valve are closed in one position and the other two are closed in the second position.

The valve area in the open position is 0.486 sq in. This holds down the pressure drops through the valve and permits the proper venting necessary for the control sequencing.

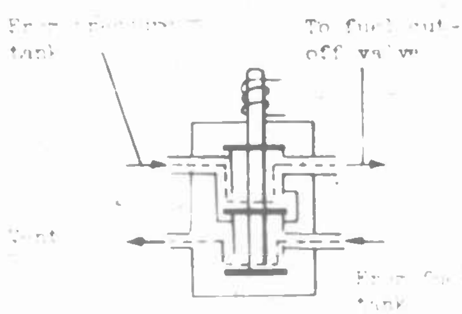
Insurance that both valves seal at the same time is made possible by the use of the resilient-rubber washer seats (20 and 28) and by final adjustment of the metal seats (16) upon assembly. The poppet assembly is normally held in the position shown in Fig. 12 by spring (33), mounted between the bottom of the solenoid housing and a shoulder on the movable poppet.

The movable solenoid core is hollow to prevent an air cushion from forming between the core and the solenoid body (5) as the core moves upward. The main-poppet shaft (25) is hollow for weight-saving reasons and is vented at both ends to eliminate any end loads on the poppet.

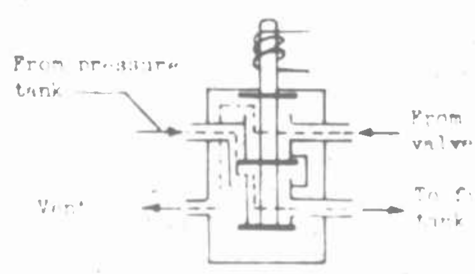
The over-all weight of the valve, including solenoid, is 5.5 lb, and it operates at normal aircraft voltage (24 volts).

Operation

When the 4-way valve is in its normal position and the main on-off valve is opened, the high-pressure gas flows through the pressure regulator into inlet port (7) of the 4-way valve. It enters the central portion (8), flows through the space between the upper insert (16) and the washer seat (28), and out through port (10). From here, gas flows to the pneumatic servo of the combustion chamber cutoff valve. At the same time, the alcohol tank is vented past the lower-washer seat (20), through the space between the splines (34) on the nut (21), and out port (12) to the atmosphere.



Normal Position



Energized Position

When the liquid oxygen at the injector inlet reaches the preset value of the pressure switch, the 4-way valve is energized and reverses itself. The movable solenoid core (31) is forced upward against the stationary core (5). Pressurized gas from the central chamber (8) then flows downward and out port (11) to the fuel tank. The fuel cutoff valve is simultaneously vented upward through port (10), around the now open valve seat (20), and out port (12) to the atmosphere.

Attention may be directed to the completely balanced design of this 4-way valve, a feature which minimizes the current drain on the solenoid since, once the valve is "cracked," the high-pressure gas (284 psi) aids both in opening and in keeping the valve open.

Combustion Cut-off Valves

The operational B-series JATOS employed three versions of fuel cutoff valve. That in the B-8 had a truncated, conical rubber sleeve in the head of the combustion chamber. The B-8a utilized two different versions of a pneumatically operated, soft-seat poppet valve centrally located in the chamber head.

Version 1 (B-8) (See Fig. 13)

The B-8 alcohol cutoff valve operated on the principle of holding the alcohol in check by applying gas pressure to a rubber diaphragm (1), which is clamped in place between the inner and outer heads (2 and 3) of the combustion chamber. (Relevant portions of the assembly are shown in Fig. 13.) When pressure is released, the alcohol presses the diaphragm outward against a backing plate, thereby permitting flow to begin. The backing plate, which supports the rubber diaphragm in the retracted position, has several small holes to equalize the gas pressure over the entire area.

It will be seen that, unless the rubber is preloaded (i.e., slightly stretched) alcohol will dribble into the combustion chamber before starting, when the unit is in the "off" position.

The rubber sleeve is a truncated cone having the following dimensions:

Large diameter	8.3 in.
Small diameter	4.5 "
Length	5.5 "
Thickness	.10-.12 "

When the unit is started, high-pressure gas from the regulator flows through the solenoid valve (Fig. 3, part No. 14) to the outer head (3) of the combustion chamber. The gas flows through the holes in the backing cone and holds the rubber against the fuel-injector inlets as well as against the outlet holes from the combustion-chamber cooling jacket. This effectively blocks the flow of fuel until the solenoid valve is energized, at which time the pressure surrounding the rubber valve is vented to the atmosphere and the fuel is simultaneously pressurized. The rubber diaphragm is thus forced outward against the backing ring by the fuel pressure, and the fuel is allowed to flow through the injectors into the chamber.

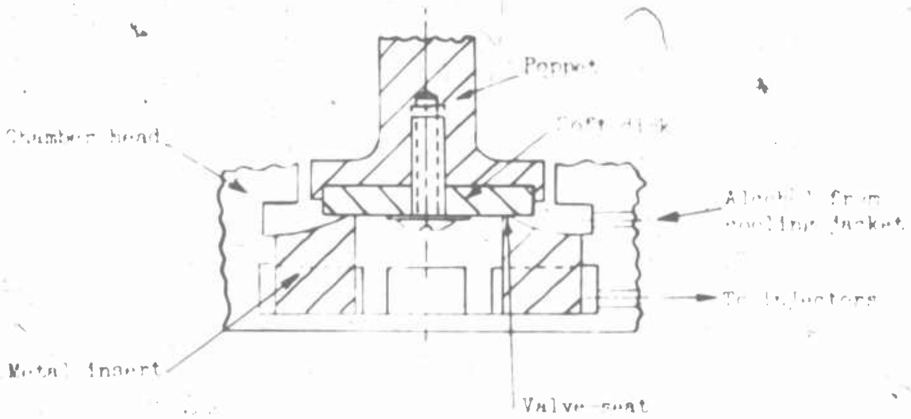
Despite the fact that this valve operated successfully, it had to be abandoned because of two difficulties caused by other system elements. It will be seen that there is an excellent path for heat transfer between the inner surface of the diaphragm and the oxygen injector. Experience showed that, if the timing was slightly abnormal, the rubber froze. Then, when the pressurized fuel entered, the rubber cracked and the valve failed.

The second difficulty arose from the occasional combustion flashbacks through the injector holes, which burned the rubber. The cause for these flash backs was not definitely known, but it appears to have been the low pressure-drop characteristics of the injector.

Version 2 (B-8 a) (See Fig. 14)

The troubles experienced with the B-8 combustion cutoff valve forced Peenemunde to a new design. The new valve was intended to shut the fuel supply off abruptly and prevent afterburning. It was, therefore, located in the center of the chamber head and as close as possible to the injector holes. Thus the volume of alcohol flowing into the chamber after shutoff was held to an absolute minimum.

The valve is screwed into the center of the combustion-chamber head (8) and seals between a special steel insert (1) and a soft synthetic-rubber washer (3). The insert is shrunk into the chamber head between the fuel-inlet holes (9) and the injector holes (10). The valve seat itself is a relatively sharp-edged lip projecting outward from the inside diameter of the insert, as shown in the sketch below:



The soft rubber disk (3) is held in a recess in the poppet (2) by a large button-head screw (4). The only means provided for locking this screw is the friction of the rubber against the poppet and the screw head. The poppet slides in a bored hole in the chamber head, and it is prevented from cocking by guide vanes sliding on the inside diameter of a special nut (6) screwed into the chamber head. Leakage past the threads is prevented by an AN-902-type gasket. A gasketed fitting (7) permits the attachment of the pneumatic actuating line from the 4-way solenoid valve. Leakage between the pneumatic and hydraulic portions of the valve is prevented by a flexible metal bellows (5), which is soldered to both the poppet and the poppet guide fitting (6). The bellows not only seals the two effectively but also acts as a spring and keeps the poppet in a normally closed position before operation.

When the engine is started, pressurized gas from the 4-way valve (Fig. 12) enters through fitting (7) and acts against the inside face of the poppet (2). This forces the poppet and its integral seat (3) tightly against the insert seat (1) and blocks any flow of alcohol from the cooling jacket into the chamber. When the 4-way valve is energized, the pneumatic portion of the combustion cutoff valve is vented to the atmosphere. The now pressurized fuel reacting against a portion of the outer face of the poppet forces it against the bellows and cracks the valve open. As soon as the poppet lifts off the seat, a considerably greater area is exposed to the fuel pressure and the valve quickly opens until the poppet stops against the skirt of the guide tube (6). Full alcohol flow then enters the chamber.

At combustion cutoff, the 4-way valve is returned to its original position, the pneumatic portion of the valve is again pressurized and the fuel tank vented. The cutoff valve is thus forced closed, the fuel supply is cut off, and combustion stops abruptly.

The closeness of fit required between the outside diameter of the poppet and its guide in the chamber head (8), the fit and concentricity requirements of the poppet guide vanes, and the inside diameter of the fitting (6) caused considerable operational difficulties. The poppet tended to stick, which produced erratic opening and cutoff characteristics. For these reasons the cutoff valve had to be redeveloped.

Version 3 (B-8a - RI-101b) (See Figs. 15 and 16)

The final version of the fuel control valve embodies major changes intended to overcome the difficulties of the previous versions. Positive opening and closing of the valve are now assured by using pressure. This method also eliminated any delays encountered on the build-up of alcohol pressure. In addition, constructional changes were made to simplify and eliminate the problems caused by binding.

The valve installation is shown in Fig. 16 and a 2-times scale assembly drawing in Fig. 15. The three parts of the valve are: the upper housing (1), containing the pneumatic servo mechanism; the housing (2), containing the seal assembly; and, the poppet-spring section (3), which fits into the motor head. The first two sections are joined by the hex-union nut (19) and the lower assembly is secured into the combustion-chamber head by the threads (C). Leakage is prevented by conventional rubber seals crushed between the mating surfaces.

The upper end of the valve shaft is piloted on shoulder (20) and mounts the piston. The lower part of the shaft is piloted on the surface (21), and any small misalignment in the poppet assembly is compensated for by the good detailed design of the poppet mount.

The piston consists of an aluminum plate (14) and two opposed rubber seals (12) facing in the direction of motion. They are retained in place by a washer (17) and hex nut (15). No provision is made for locking, but the resiliency of the rubber practically eliminates loosening under normal service conditions. Inasmuch as the rubber seals are soft, expanding snap-ring assemblies (13) are used to maintain seal contact with the wall.

The seal assembly in housing (2) is of a similar type. Two shaped, rubber-lip seals are mounted on the spacer disk (7) and held against the shaft by retainer rings (9).

The poppet is mounted flexibly on the end of the shaft by lockpins (4), which permit a reasonable degree of free motion and self-centering. This excellent detail feature compensates for mounting accentricities and tolerances. Lateral guidance of the poppet is achieved by the vanes (22), and the sealing is achieved by the rubber insert (5). The spring (6) holds the poppet shut in the unpressurized condition.

During the operating cycle, initial closing pressure is provided at port (A) while (B) is vented. Then, port (B) is pressurized while (A) is vented. This results in a positive action of the valve under both conditions. The pressure changes and their relations to the other system elements have been described above in connection with the 4-way valve and the B-8a operation.

The positive operating characteristics of this version of the cutoff valve satisfactorily met the system requirements.

Schmidding G-1 (See Figs. 9 and 10)

Component Arrangement and Critique

The Schmidding Company received the assignment of making a production version of the B-series JATOS developed at Peenemunde. Upon consideration, they decided to use the B-7 combustion chamber and conform to other B-series operating specifications, but to reverse the

Peenemunde trend toward comprehensive sequencing and safety circuits, they made drastic changes in the control system design, all in the direction of the absolute minimum in both propellant supply and controls.

The Schmidding G-1 redesign attempted a new spatial arrangement of the system elements. (See Fig. 10) The liquid-oxygen tank is moved closer to the combustion chamber, which is a sound change since it decreases the length of the oxygen line. But the pressure bottles are shifted forward, which moves the center of percussion forward and may impose additional stresses in landing, especially if the tail-first dropping attitude is retained.

No account is taken of the sloshing of the propellants consequent on the angle of climb. Both the liquid oxygen and the alcohol feed pipes are mounted vertically, not bent rearward as in the Peenemunde units. This increases the risk of cavitation toward the end of the run. The possibility of cavitation is further increased by the Schmidding control system, which provides for cutoff when the chamber pressure drops. Therefore, intermittant injections of propellant and gas might cause wide variations in chamber pressure, resulting in no definite cutoff point.

Performance and Operation

The high-pressure nitrogen tanks are filled through valve (13) (Fig. 9) and the fuel and liquid-oxygen tanks through their respective fill connections (not shown). In order to initiate combustion, the system must first be armed by opening the high-pressure hand valve (10) and closing the main electrical contact switch (17). The former allows the high-pressure nitrogen to flow through the filter (12) and through the pressure regulator (5), where it is reduced in pressure and stopped by both the pneumatic valve (9) and the pilot valve (14). The latter operation electrically connects the two JATOS in parallel to the electrical power supply and control switches in the aircraft.

When the pilot desires thrust, he pushes the start button. This starts the single igniter (7) and energizes the solenoid pilot valve (14), thus permitting the nitrogen gas to open valve (9). Pressure-regulated gas now flows to each of the propellant tanks: directly into the oxygen tank (2) over a deflector plate (11) (to limit nitrogen absorption by the liquid oxygen), through a 3-way ball-check valve (6) into the alcohol tank (1).

The alcohol tank is normally vented through the 3-way check valve (6). The incoming gas closes the vent port and flows into the tank through the lower leg of the " T" valve.

The liquid oxygen flows into the chamber (3) through a ball-check-valve injector (8). When it reaches the preset pressure, it opens the fuel cutoff valve (15) and allows the pressurized fuel to enter the combustion chamber. The propellants are ignited by the pyrotechnic igniter (7), and thrust continues until the fuel is exhausted and the chamber pressure drops below 100-110 psi. At this point the pressure switch (16) opens and stops the operation of both JATOS simultaneously.

To permit starting, pressure switch (16) is initially by-passed by a bimetallic bridge which takes four seconds to heat up enough to open. By this time the chamber pressure has built up to the point where it exceeds the cutout limit of the pressure switch; hence, the engine continues to operate until the propellants are exhausted or the pilot opens the main switch.

After cutoff, both tanks vent through valve (9) until the pressure has dropped below that required to hold the ball-check vent valve (6) closed. As soon as this valve opens, the fuel tank vents through the now open port and the liquid oxygen tank continues to vent through valve (9).

If operation is discontinued by the pilot's opening of the main switch, valve (14) is closed and the tanks are vented as above. No possibility of restart exists because of the use of a powder, one-shot igniter.

Schmidding claimed that their glass-wool-insulated oxygen tank would permit the engine to stand for approximately 10 hr before use without serious detriment to the total impulse. This appears to be a considerable exaggeration, since the fully loaded liquid-oxygen tank contains only enough to meet the thrust and duration requirements. Accordingly, any evaporation would reduce the operating duration.

G-1 Safety Circuit

The G-1 safety circuit provided the simplest type of protection against major operating mishaps. No attempt was made to cover the finer points of operation. Thus, to achieve a very minor saving, only one igniter was used. 4/ The operational and safety devices summarized below are integral parts of the control circuit.

Four major safety precautions were incorporated. These are:

1. The propellant tanks may not be pressurized until the pyrotechnic igniter is operating.

2. The oxygen-piloted fuel cutoff valve (15) assures the prior entry of oxygen into the combustion chamber.

3. Operation of the unit is cutoff when the chamber pressure drops to approximately 100-110 psi, 75% of normal.

4. Cross contamination of the alcohol and oxygen vapor is normally prevented by venting the alcohol through the 3-way check valve (6) and the oxygen vapor through the main 3-way valve (9).

Summary and Evaluation of the Peenemunde B-Series

The design characteristics of the units analyzed in this sequence are summarized in Table 2. As indicated, the German Air Ministry retained their specifications throughout the entire course of the development program. The same propellants were used for the same thrust and duration, and the requirement for positive interlocking of the JATO operating steps persisted.

The summary and comparative evaluation of these units, therefore, focus attention on the interpretations which the control designers gave to these requirements. Inasmuch as the B-8a was the culmination of the Peenemunde B-series, it may well be compared with the G-1. Both systems used identical propellants, substantially the same combustion chamber, chamber pressure, ignition system, and pressurizing medium. Major differences were in the safety circuits and provisions for operational checks.

4/ Schmidding claimed more than 100 successful tests with his igniter. However, these were made under much more favorable conditions than obtained in the field. Both foreign and American experience indicate that powder squibs and pyrotechnic igniters frequently become unreliable after storage and field handling. For example, the starting system of the A-4 was such that the operator could shut down the engine if he saw that the pyrotechnic igniter was not operating successfully.

Schmidding claimed that their glass-wool-insulated oxygen tank would permit the engine to stand for approximately 10 hr before use without serious detriment to the total impulse. This appears to be a considerable exaggeration, since the fully loaded liquid-oxygen tank contains only enough to meet the thrust and duration requirements. Accordingly, any evaporation would reduce the operating duration.

G-1 Safety Circuit

The G-1 safety circuit provided the simplest type of protection against major operating mishaps. No attempt was made to cover the finer points of operation. Thus, to achieve a very minor saving, only one igniter was used. 4/ The operational and safety devices summarized below are integral parts of the control circuit.

Four major safety precautions were incorporated. These are:

1. The propellant tanks may not be pressurized until the pyrotechnic igniter is operating.
2. The oxygen-piloted fuel cutoff valve (15) assures the prior entry of oxygen into the combustion chamber.
3. Operation of the unit is cutoff when the chamber pressure drops to approximately 100-110 psi, 75% of normal.
4. Cross contamination of the alcohol and oxygen vapor is normally prevented by venting the alcohol through the 3-way check valve (6) and the oxygen vapor through the main 3-way valve (9).

Summary and Evaluation of the Peenemunde B-Series

The design characteristics of the units analyzed in this sequence are summarized in Table 2. As indicated, the German Air Ministry retained their specifications throughout the entire course of the development program. The same propellants were used for the same thrust and duration, and the requirement for positive interlocking of the JATO operating steps persisted.

The summary and comparative evaluation of these units, therefore, focus attention on the interpretations which the control designers gave to these requirements. Inasmuch as the B-8a was the culmination of the Peenemunde B-series, it may well be compared with the G-1. Both systems used identical propellants, substantially the same combustion chamber, chamber pressure, ignition system, and pressurizing medium. Major differences were in the safety circuits and provisions for operational checks.

4/ Schmidding claimed more than 100 successful tests with his igniter. However, these were made under much more favorable conditions than obtained in the field. Both foreign and American experience indicate that powder squibs and pyrotechnic igniters frequently become unreliable after storage and field handling. For example, the starting system of the A-4 was such that the operator could shut down the engine if he saw that the pyrotechnic igniter was not operating successfully.

Table 2

Design Characteristics of the Peenemunde B-Series JATOS

	B-7	B-8	B-8a	G-1
Thrust (lb)	2200	2200	2200	2200
Duration (sec)	32	30	30	30
Oxidizer	Liquid Oxygen	Liquid Oxygen	Liquid Oxygen	Liquid Oxygen
Fuel	Alcohol	Alcohol	Alcohol	Alcohol
Pressurizing Medium	Nitrogen	Nitrogen	Nitrogen	Nitrogen
Total Weight (lb) 1/	830	~910	1050	~850
Empty Weight (lb) 1/	415	490	585	475
Length (in.) 1/	92	101	100	84
Diameter (in.)	27.5	28.7 wide 43.3 high	35.5	31
Ignition	1 Pyrotechnic	2 Pyrotechnics	2 Pyrotechnics	1 Pyrotechnic
Cutoff	Fuel Low Level + Pneumatic Valve	Low Fuel Flow + Pneumatic Diaphragm	Fuel Low Level + Pneumatic Valve	Chamber Pressure Drop + Pneumatic Valve
Length of Electrical Wire (ft)	59	~75	115	10
Allowable Standing Time Before Start (While Still Meeting Impulse Requirements)	15 min	~4-5 hr	~5 hr	0
Number of Starts	One Time	One Time	One Time	One Time
Type of Controls	Hand, Solenoid, Pneumatic	Hand, Solenoid, Burst Diaphragm	Hand, Solenoid, Pneumatic	Hand, Solenoid, Pneumatic
Availability of Controls Components	Commercial + Special	Special	Special	Commercial
Utilization	Test	Prototype	Intended Production	Intended Production

1/ Includes parachute.

Pressurizing Circuit

The B-8a pressurizing circuit incorporated the following safety factors: a pressure gage integral with the electric circuit, which prevented starting unless the nitrogen tank was at the desired pressure; and an electrical check on the operation of the hand on-off valve.

The G-1 has no safeties in this part of the circuit. Accordingly, it must be carefully checked on the ground before loading. Thus, a higher responsibility is placed on the ground crew, but weight saving is achieved without substantially increasing the hazards of operation.

Propellant Supply Circuit

The B-8a provides separate tank vents and a positive level indicator for the oxygen tank. The combustion chamber jacket fills with alcohol by gravity and the jacket is automatically vented to prevent the trapping of bubbles.

The G-1 oxygen vent line also serves as the main pressure line to the oxygen and alcohol tanks during operation. This would imply that the initial surge of pressure into the alcohol tank is extremely oxygen rich. However, as the absolute quantity is small, it is unlikely that an explosive mixture would result.

The G-1 has no oxygen-level indicator; because of the fact that no excess of oxygen is provided for evaporation, it is most unlikely that full impulse would be reached with this unit under normal operating conditions. Provision for venting the combustion-chamber jacket is also omitted, so that there is danger of air being trapped. This may act to change the timing somewhat, but, inasmuch as it is the alcohol which is delayed, the direction of the timing is not affected and the hazard is only marginal.

Timing and Ignition Circuit

The B-8a and the G-1 employ substantially the same timing and ignition circuits. The B-8a uses a solenoid operated four-way valve as its main control, an oxygen pressure switch to insure the timing of propellant entry into the chamber, and two igniters. The G-1 uses a solenoid piloted pneumatic valve as its main control, retains the system of using the oxygen pressure to pilot the alcohol injection, but reduces the number of igniters to one.

The G-1 main pneumatic control valve appears to be superior in conception to the Peenemunde solenoid valve since it does not have the high-current drain characteristic of the latter. The elimination of one of the igniters in the G-1, however, is a saving of doubtful utility and represents a weak point of the design.

The starting of both the B-8a and the G-1 required that the ignition cutoff be by-passed. The B-8a used a pneumatically damped pressure switch, while the G-1 used a bimetallic switch. The bimetallic type appears to be simpler and more reliable.

Normal and Emergency Shutdown

The B-8a was normally shut down by propellant exhaustion. A pressure switch was placed in the oxygen line and a flow-operated switch in the alcohol line. When either the pressure or flow fell below the set point, both JATOS were shut down. No provision was made for the variations in the chamber pressure.

The G-1 used a simple chamber-pressure switch for both normal and emergency cutoff. This was a logical choice since flow and combustion variations reflect themselves directly in the changes in chamber pressure. Accordingly, the G-1 represents both a simplification and weight saving.

Application to American Practice

The application of the control system elements of the Peenemunde B-series JATOS to American practice is considered in the following table.

Table 3

Applicability of Peenemunde B-Series JATO Control Components to American Use

Unit	Component	Recommendation for American Use	Remarks
B-7	Liquid-oxygen-tank fill valve capped with safety burst diaphragm	Yes	Conventional.
B-8	Burst-diaphragm gas valves	Yes	For one use only-simple, inexpensive, lightweight; replaces large current-drain solenoid valve for main gas-pressure on-off valve.
B-8	3-way ball-check vent valve	Yes	Simple, self-centering, positive seal, low maintenance.
B-8	Two 3-way solenoid sequencing valves	No	4-way solenoid does same work for less weight.
B-8	Rubber diaphragm fuel-cutoff valve	Yes	Simple, lightweight, positive seal. (Should not be used near liquid oxygen.)
B-8	Double pyrotechnic ignition	Yes	For single use anergole propellant systems. Two more reliable than one.
B-8 and B-8a	Liquid-oxygen-level indicator	Yes	As liquid oxygen evaporates, the impulse declines.
B-8a	Solenoid main gas-pressure on-off valve	No	Too high-current drain - pneumatic or burst-diaphragm valve, piloted by a small solenoid valve, recommended.
B-8a	Cooling-jacket vent valve	Yes	Removes air from jacket - insures proper and reproduceable timing when fuel is stopped before entering chamber.
B-8a	Fuel-flow indicator	No	Too complex - chamber-pressure switch effective and simpler.
B-8a	4-way solenoid	Yes	Simple-balanced design requires low current drain, provides fail-safe operation as well as positive sealing.
B-7, B-8a and G-1	Gas filter	Yes	Prevents particles of dirt and rust from damaging or clocking pressure regulator and other pneumatic valves. Conventional.

Table 3 (Cont'd)

Applicability of Peenemunde B-Series JATO Control Components to American Use

Unit	Component	Recommendation for American Use	Remarks
G-1	Pneumatic-operated gas on-off valve	Yes	Eliminates large solenoid valve; hence heavy battery drain.
G-1	Chamber-pressure switch	Yes	Reliable and simple for safety and final shutdown. Conventional.
G-1	Single igniter	No	Not as reliable as 2. Weight saving insignificant.

C-2 (WASSERFALL)

Design Data

The design data determining the control system of the C-2 may be considered in accordance with the outline presented in the Introduction.

Mission - The C-2 was intended as a single application, antiaircraft rocket missile. It should be capable of being stored for long periods and fired without major ground checks.

Thrust and Duration - The thrust was to be constant at a value of 17,600 lb for 45 sec.

Altitude, Range, and Velocity - The missile must be able to intercept enemy aircraft at an altitude of 65,000 ft, 30 mi away, at a missile velocity of 1150 mph. This was later scaled down in altitude to 32,500 ft, which was considered adequate for the immediate needs. The thrust and duration given above theoretically fulfilled these requirements. However, excessive weight of the propulsion unit (over the 2100 lb specified) decreased the range considerably, as evidenced by test-flight reports.

Flight Attitude - Combustion was to be maintained within ± 20 degrees of vertical flight.

Propellants - Mixed acid and Visol.

Propellant Feed System - Pressure.

Propellant Ignition - Hypergole propellants.

Weight - The initial empty-weight requirement for the propulsion unit (including motor, tanks, controls, and lines) was 2100 lb.

Space Limitations - The component arrangement had to conform with the missile's length-to-diameter ratio of 9:1.

Scale of Utilization - The mass scale of utilization contemplated for this missile (5000 per month) rendered essential a minimum use of critical materials. A concomitant requirement was the utmost simplification of construction to reduce the need for special tools and skilled labor.

Interrelation of Component Design Factors

Propellant Selection

Since the propellants selected for the Wasserfall form a hypergole combination, no ignition system was required.

The corrosive properties of the acid has a definite effect upon the control system components in relation to the scale of manufacture and materials limitations. The mass-production requirement, coupled with the shortage of high-quality metals, made it necessary to design around the corrosive quality of the acid in order to use more readily available metals. Thus, the acid and fuel were held in their containers until the moment of use, so that they were not in contact with the control-system elements for longer than the duration of operation. This made it possible to use low-quality materials.

Propellant Feed System

Two different pressurizing methods were proposed: the first, a compressed gas feed using a nitrogen tank; the second, a self-contained steam generator system. The control designs arising from these alternatives are covered below in detail.

Operation at an Angle

The requirement for operation at an inclined angle rendered necessary the use of the swing-pipe collector system. (See APJ Report No. 51-0-12H Vol. V.) The swing pipe was intended to follow the motion of the propellant and reduce the hazard of gas cavitation in the feed lines.

Constant Thrust

The constant-thrust flight program demanded the use of a regulator to compensate for the variation in pressure of the nitrogen gas. In the steam-generator version it was possible to eliminate the main regulator and substitute, instead, a smaller regulator as a part of the steam-generator circuit.

The influence of thrust program on control systems is the subject of APJ Report No. 51-0-12D (Vol. VII).

Metallurgical Requirements

Metallurgical requirements follow as a consequence of the design data. Components of the system which would be in contact with the acid for long periods had to be made of high-quality materials. These were held to the minimum and included only the tank, swing pipe, and burst diaphragm. The remainder of the unit could be made of low-alloy steel (1604 or 1265). Even the aluminum valves were of thick-wall construction to permit the use of secondary aluminum. Elsewhere, standard aircraft design and material specifications were applied wherever possible.

Design Sequence and Operating Characteristics

First Operational Version

The first operational version of the C-2 to be intended for mass production employed a swing-pipe pressure system with nitrogen as the pressurizing medium.

Component Arrangement (See Fig. 17 - SKW 820C)

The control elements of this unit were as follows:

1. Nitrogen-pressure sphere, of welded steel construction.

2. Regulator assembly. Construction details and operation are discussed below.

3. Propellant tanks with swing pipe. The arrangement of propellant tanks and lines followed the Peenemunde conception of running the propellants through tubes located in the center of the tanks. Minimum drag was thus attained, but it undoubtedly imposed a weight penalty as well as added difficulty in manufacture. 5/

   The propellant collectors are of the type discussed in APJ Report No. 51-0-12H (Vol. V). They consisted of a swing collector from which the propellant flowed through an annular chamber, thence through ports, into the main fuel pipe. This arrangement apparently operated at ±35° to 45° of the vertical, which more than satisfied the 20° requirement of the RLM. 6/

4. Propellant control-valve assembly. Structural details and operation of this sub-assembly are discussed below.

5. Combustion chamber. There are no control elements in the combustion chamber, but attention may be called to the flexible connections (14 and 15) which compensate for expansion, alignment, and vibration.

Operation (See Fig. 17)

The propellant tanks are filled through connections in the cylindrical portion of each tank. The location of the fill connections and the fact that no venting procedure is provided indicate that units were to be filled in a horizontal attitude. The pressure tank is charged through check valve (2) and may be checked through the tap (16), which is carried through to the lower portion of the missile in order to obviate the need for ladders when the unit is mounted vertically, prior to take-off. This tap also permits any make-up pressure to be added at the time of fire.

The unintentional start of the unit due to the release of compressed gas from excessive gas expansion or high-pressure valve failure was prevented by a vent valve 7/ (Fig. 19, part 7) located at the exit of the regulator. In normal position, this valve closes the regulator exit to the tanks and vents to the atmosphere.

Before the unit is started, an electrically activated powder squib on the vent valve is ignited. This opens the regulator exit to the tanks and closes the vent. The missile is now armed and a check lamp lights in the ground station control room. The launching process may now be initiated. The powder cartridge in valve (4) (Fig. 17) is electrically ignited by closure of the remote-control start switch. Expanding gas from the cartridge forces the backing plug away from the metal diaphragm and allows the pressurized nitrogen to burst the diaphragm and flow through the pressure regulator (6). The nitrogen is reduced from 3700 psi to 355 psi and bursts diaphragms (5) as soon as the pressure exceeds approximately 142 psi.

5/ Several American units, e.g., the WAC Corporal, have used external propellant lines without detriment to performance.

6/ Analysis of flight-test reports discloses numerous instances of uneven thrust due, apparently, to gas cavitation. These were most frequent near the end of the run. In cases in which guidance failure produced angles of pitch greatly exceeding 30°, failure of the propellant feed system must be attributed to the guidance.

7/ Sometimes designated by the Germans as a "3-way valve."

Both propellants are then pressurized and forced through their respective outlet pipes (13) to diaphragms (7), which also burst at about 142 psi. The oxidizer and fuel flow through the propellant control valve (11), - the fuel flows directly through the injector into the combustion chamber, while the acid flows through the cooling jacket of the motor before entering the injector and chamber.

Since these propellants are hypergolc, ignition takes place as soon as they come into contact with each other, and thrust continues until the propellants are depleted. No possibility of shutoff exists, once valve (4) is energized. However, neither shutoff nor restart were prerequisite for the mission of the C-2, and the simplest possible controls were used to advantage.

Valves

Two major control assemblies are employed in this version of the C-2: a pressure regulator assembly and a propellant control valve. Both contain numerous design features of interest and are, therefore, discussed in detail.

Pressure Regulator Assembly (See Fig. 19)

In addition to its function as pressure regulator, the regulator valve assembly also acts as nitrogen fill valve, strainer, burst valve, high-pressure relief valve, surge control, and vent. While the individual components are of fairly conventional mechanical design, taken together they represent an ingenious means of meeting the mission requirements. Ease of storage, low cost, and positive safeties are all included.

Component Arrangement and Critique

The four main parts of the assembly are: high-pressure valve assembly, regulator, surge damper, and vent valve.

1. High-Pressure Valve Assembly

The high-pressure valve assembly consists of a nitrogen-fill connection (1), strainer (4), powder-cartridge burst valve (5), and high-pressure relief valve (3). The welded bracket mount for the fill connection proved unsatisfactory, however, because it broke easily under vibration. The fill connection was later relocated, therefore, and screwed into a fitting near the strainer.

The strainer (4) is of conventional design, embodying no new features.

The cartridge burst valve appears to have been well worked out. Its piston is backed by a thin diaphragm. When the cartridge (9) is fired, the piston retracts violently and jams itself into its seat. The diaphragm breaks and nitrogen flow begins. In practice, however, the piston-poppet connection was destroyed whenever the cartridge was fired with unusual violence.

The high-pressure relief valve (3) is a heavily loaded needle valve intended to protect the high-pressure tank. If, for any reason, such as excessive temperatures, pressure builds up in the nitrogen tank, this valve provides automatic relief. A pressure deficiency, on the other hand, is eliminated before firing, through the check valve and tap (2 and 16, Fig. 17) previously described.

2. Regulator

The regulator (6) is of the conventional, spring-loaded type. It is large and heavy, but the detailed design appears to be good. For example, the regulated pressure is by-passed to the top of the sealing piston in order to balance the action of the regulator and maintain rated output.

3. Surge Damper

The surge damper (8) represents a novel feature. The lines and tanks are protected from the first flow of high-pressure gas by a soft-seat, spring-loaded relief valve which is forced open during the first instant and then returns to seal when regulated pressure begins to flow. This feature reduces the design safety factors, which would otherwise be required in both line and tank dimensions, and results in a considerable weight saving.

4. Vent Valve

The vent valve (7) provides the positive safety control of the unit. It is a pneumatic servo-operated, 3-way 8/ valve, which is normally closed with vent ports open. If the burst valve (5) and diaphragm should fail, the high-pressure would merely exhaust to atmosphere without causing a premature start of the engine. The valve is set in motion by electrically firing cartridges (10 or 11), which are approximately .25 caliber.

Gas released by cartridge (10) drives the piston to the open position, thereby closing the vent and connecting the pressure source with the tanks. Simultaneously, the piston shaft closes contacts (12), flashing the "Ready" signal to the ground operator. If it is desired to safety the system again, firing cartridge (11) returns the vent valve to its original position. The difficulty with these cartridges, however, was that they were so sensitive to power input and to shock that, according to records, spontaneous ignition was occasionally caused by thunder storms.

The mechanical construction of the servo piston and guidance was not fully satisfactory either, inasmuch as cocking was sometimes encountered.

Operation and Critique

The operating cycle of the pressure regulator assembly proceeds in a straightforward manner. When the missile is ready to be fired the operator fires cartridge (10). This closes the vent valve (7) and contacts (12), and signals the operator that he may fire the burst valve (5). The withdrawing of the backing piston permits the high-pressure gas to burst the diaphragm, pass through the regulator, and into the tanks. Initial pressure surges from the regulator are taken up by the damper (8).

If, after firing the vent valve, the operator should decide not to launch the missile, he may shut off the unit by firing cartridge (11), thereby reopening the vent. In this case, both cartridges (10 and 11) must be replaced before the C-2 can be launched. Their position well up in the missile body makes access and replacement difficult, but this contingency is rare and may be regarded as an emergency measure only.

Propellant Control Valve (See Fig. 20)

The propellant control valve exercises the function of a mixture-ratio control and timing valve. Since the propellants are hypergole and the proper selection of line sizes and orifices should automatically set the mixture ratio within fairly close limits, this valve might seem to be superfluous. It was included, however, in an attempt to improve the timing and to start the combustion gradually. Hard starts in combustion chambers of large thrust may cause very high transient pressures, with consequent risk of failure. An analysis of Wasserfall flight-test data supports this conculsion.

8/ This nomenclature is adhered to for reasons of consistency with the German designations. Actually, the valve has four connections: pressure, tank, damper, and vent.

Nevertheless, the latest C-2 proposal (SKW 1145C of Feb 1945), discussed below, eliminated the propellant control valve. The 109-548 and 109-558 were also designed without one.

Two subassemblies comprise the propellant control valve. The first consists of two butterfly valves yoked together and a pneumatic actuating servo. The second is a pneumatic pilot valve (Fig. 22) which fires the servo.

Design, Construction, and Materials

Butterfly Valve Assembly

The design of the propellant control valve may profitably begin with a consideration of line sizes, since they determine the inside diameters of the valve, as well as design details such as flanges and attachments. The main valve assembly is housed in a hollow cast-aluminum block 12.8 in. long, 5.9 in. wide, and 5.1 in. deep.

The diameter of the acid port is 2.75 in., of the Visol port, 1.55 in. The actuating valve assembly is 9.8 in. long and about 1.4 in. in outside diameter. The total valve assembly weighs 13.4 lb.

The attachments and flanges are of normal design but are considerably smaller than that which German standards would normally require for a working pressure of 300-350 psi. The inlets and outlets of each valve are bolted to flange-type pipe fittings on the lines, as shown in Fig. 21. The joints between the valves and the flanges are sealed by metal-to-metal, pointed, tongue-and-groove seals.

The wall thickness of the valve assembly may be checked according to the conventional formula:

$$s = \frac{pr}{t}$$

where: s = tensile yield stress ($\sim$10,000 psi)
p = maximum working pressure ($\sim$320 psi)
t = wall thickness (in.)
r = mean radius (1.5 in.)

Solving for t:

$$t = \frac{pr}{s} = \frac{320 \times 1.5}{10,000} = 0.048 \text{ in.}$$

Assuming a safety factor of 6, the wall thickness is 0.048 x 6 = 0.288 in. which closely checks the actual size. The liberal safety factor and the extremely low tensile-yield stress selected permit the use of secondary aluminum castings with only minimum rejections.

The acid and Visol butterfly valves (2 and 3, respectively) 9/ are separated and aligned by the two cast webs of the main housing (1). The valves are elliptically shaped.

9/ The German number of Fig. 20 is SKW 3902.1039, and its various parts are designated by the drawing number / an additional number. For example, the acid valve is numbered SKW 3903. 1039/2. To simplify references in this discussion, only the final, or part number, is used. Thus, the acid valve is here referred to by the number (2).

cast-metal disks, machined to fit snugly into the cylindrical bores of the housing. The 2 disks are fastened to a common shaft (4) by short cylindrical pins (DIN 1473). 10/ The shaft is mounted in bushings (5 and 6) on either side of each valve, and it is sealed by synthetic-rubber cup seals (19 and 20). The seals are backed up by metal washers (22 and 23) and held in place by snap rings (DIN 472). Tubular spacers (7 and 8), which act to hold the lips in place, also separate the seals from the bushings. The central portion of the shaft is pinned to a sleeve and rocker arm assembly (Ui) by a cylindrical pin (DIN 1473). The arms are pressed on the sleeve and kept from rotating by flats on both mounting holes.

Because of their construction and metal-to-metal surfaces, the butterfly valves do not offer a positive seal in their closed position. This is acceptable, however, inasmuch as they are only regulators, not on-off valves. The maximum allowable leakage of 2.1 ± 0.5 quarts per sec of Visol and 5.2 ± 0.5 quarts per sec of acid is not serious, since frangible diaphragms in the propellant lines (Fig. 17, part no. 7) prevent propellant flow until the C-2 is fired. After the diaphragms burst, the valves remain closed for so short a time that the total leakage is insignificant.

Butterfly valves greatly simplify the design problem because they are very easy to mount and are practically balanced in all operating positions. The only force required to move them is that necessary to overcome the mechanical friction and the slight closing force in the half-open position, caused by suction on the downstream side. The use of simple sleeve bearings and standard cup seals held in place by standard snap rings is good design practice where costs must be minimized.

The pneumatic actuating servo (section A-B) is slid through holes in the main housing webs and is secured in position by a snap ring (DIN 471) on the bottom and a hex nut (DIN 936) on the top. Two flats on the bottom part of the actuator housing (9) are held by a wrench while the upper nut is tightened. The actuator housing is open at the bottom and closed at the top by a special hex-held cap (10), the upper part of which is threaded and fastened to the tube from the pilot valve. (See Fig. 21.) The cap (10) and the hex nut (DIN 936) are lockwired together and to the main housing (1), and the lockwire is sealed by a lead seal (DIN 9043) to prevent tampering with the inlet bleed setting.

The center portion of the cap (10) is drilled and tapped at the top to receive a needle-valve screw (17). This screw has a hole 3/64 in. in diameter drilled longitudinally through its center, to withing 3/32 in. of the point. An outlet of similar size is drilled at right angles to this hole, about 5/32 in. up from the point. The bottom of the cap also has a 3/64-in. diam. hole, drilled longitudinally through its center, in line with the needle valve. The location of the needle-valve point relative to the top of the hole in the bottom of the cap determines the orifice through which the pneumatic pressure is applied to the actuating valve. The orifice setting is maintained by a spanner-type locknut (DIN 546).

Entry of the nitrogen pressure into the actuating cylinder is restricted by the needle valve, permitting a slow build-up of propellant flow (approximately 2-3 sec), and avoiding rough starts which would otherwise result.

The pressure adjustment is made available because the valve timing is critical and some compensating means must be provided for the friction forces, which cannot be calculated, and the manufacturing tolerances, which are unpredictable. An adjustable needle valve is the easiest and most accurate way to adjust the inlet gas bleed.

The length of the actuator valve is determined from the height of the main valve, the length of the return spring, and the gas-inlet fitting. The diameter depends upon the

10/ German DIN numbers indicate standard parts, similar to American AN standards.

spring design and the available gas pressure. If an aluminum pin of approximately 0.5 in. diameter is assumed to be reasonable to transmit the valve motion to the rocker arm assembly, then the actuator shaft through which the pin passes must be at least 0.7 in. in diameter. The inside diameters of the piston and spring are set by the outside diameter of the actuator shaft.

A spring with an inside diameter of 0.75 in. (permitting clearance over the shaft), having a stroke of 2.15 in. (60° motion of the butterfly valves at the required distance), and an estimated closing force of at least 25 lb, has the following dimensions: 11/

Mean diameter = D	= 0.88 in.
Wire diameter = d	= 0.15 in.
No. of active coils = N	= 14
Total coils	= 16
Solid height	= 2.4 in.
Material.	= Brass
Spring rate = p/f	= 36 lb/in.
Mounted length	= 4.5 in.
Load at rest (assumed)	= 25 lb
Load at solid height	= 25 lb + (36 x 2.15) = 102.5 lb
Stress at 102.5 lb	= 68,000 psi

The force available to overcome the spring force + the friction = the nitrogen pressure x the piston area.

$$F = pA = \frac{p \pi d^2}{4}$$

where: F = actuating force
p = nitrogen pressure = 350 psi
d = diameter = 1.08 in.

$$= 350 \times \frac{(\pi \times 1.08^2)}{4}$$

$$= 322 \text{ lb}$$

The force of 322 lb is more than adequate to provide for contingencies.

Because the outer diameter of the piston is 0.15 in. larger than the inner diameter of the tube, the body of the actuator valve may be machined from standard aluminum tubing 1.4 in. in outer diameter and approximately 0.25 in. wall thickness. This is enough metal to allow for finish-mechining the bore of the valve body. A standard nut and snap ring may also be used to attach this tubular housing to the main-valve housing.

Constructionally, the pneumatic piston is a conventional synthetic cup seal (21), slid over a metal shaft (11) and fastened to it by two snap rings (DIN 471), a washer (24), and a tube (15). Another snap ring (DIN 471) holds a metal washer (24), which serves as a shoulder for the spring (12) and as a guide for the shaft (11) in the housing (9). The lower end of the spring bears against a washer-faced spring guide (14), which is held in the housing (9) by a snap ring (DIN 472). Two guide blocks (16) are fastened to shaft (11) by a pin (13) and retained by cotter pins (DIN 94). The pin (13) extends through a 2-5/8 in. slotted hole in the housing (9). The blocks (16) are free to rotate on pin (13) and slide in U-shaped slots in the arms of the rocker assembly (UI). Thus, the longitudinal motion of the actuator shaft (11) is converted into rotary motion of the valves (2 and 3). Misalignment of the actuator assembly and the valve assembly is prevented by a button-head pin (18) pressed into the actuator body (9) and slid into a slot in the lower web of the main-valve housing (1).

11/ Calculated with a Barnes-Gibson-Raymond Spring Data Computer

Pneumatic Pilot Valve (See Fig. 22)

The pneumatic pilot valve exercises a dual function: it fires the propellant valve actuator when adequate fuel pressure is obtained; until then, it keeps the actuator valve from opening by holding the nitrogen pressure in check. The pneumatic pilot valve determines the start of operation of the propellant control valve but does not influence its rate of opening.

The over-all measurements of the pilot valve are:

Length	5.35 in.
Normal diameter	1.55 in.
Weight	0.9 lb (approx)

The body (1) is a machined aluminum-alloy cylinder, tapped at both ends to receive the hydraulic and pneumatic inlet fittings (2 and 3, respectively). A threaded boss, located approximately in the center of the valve assembly, is fastened to the pneumatic line (Fig. 21) by a tube nut. The hydraulic end of the valve is bored to receive the 1-1/8 in. diam. piston (5) and the servo fluid seal (14). 12/

The piston and seal are held against a shoulder on the valve shaft (7) by a special nut (4), screwed but not locked to the shaft. The servo cylinder is capped by the inlet fitting (2) and sealed by a sharp-edged, metal-to-metal, V-shaped seal. The opposite side of the piston is vented through a 0.1-in. diam. hole and the piston motion is stopped against a shoulder in the housing bore. Leakage along the shaft is prevented by a force fit between the sharp-edged shoulder on the shaft and a 90° countersink in the lower end of the piston.

A metal poppet (6) with 90° conical facing is bolted against a sharp-edged shoulder on the other end of the shaft (7) and held in place by a nut (DIN 934). Leakage along the shaft is prevented in similar manner to that explained above for the piston. The 0.8-in. outer diameter of the poppet fits snugly into a cylindrical bore in the housing (1), and the 0.08-in. radial width slots milled in the periphery permit free passage of gas past the poppet when in the open position.

Until opened by fuel pressure, the poppet seal is normally held closed by a spring (8) mounted between the outer face of the poppet and an inner shoulder in the gas-inlet fitting (3). The inlet fitting and housing joint are sealed by a V-shaped, metal-to-metal seal and are lockwired together, as shown in the full-size view in Fig. 21. Leakage of gas past the shaft into the servo cylinder is prevented by a synthetic-rubber cup seal (13). This seal is held in the housing (1) between a pressed-in tube (9) and a washer (15) and snap ring (16).

The pneumatic pilot valve appears to be well designed and very easily constructed. Although the sequence of operation up to the action of the butterfly valves is extremely rapid, the controls selected appear to assure satisfactory and positive action. Interesting features are the use of metal-to-metal seals and the jam-fit of the poppet on the shaft (6 and 7). The cup seals follow conventional practices.

Latest C-2 Design Version

Another version of the C-2, representing some of the latest ideas of Peenemunde for its improvement, was designed in Feb. 1945. Major changes were made in the controls as a result of a change in the method of pressurization. While the earlier versions use basic pressurization, the present unit uses a steam generator instead. Evidence indicates that this change was dictated by the excessive weight of the pressure tank, which seriously interfered with the Wasserfall's performance and, indeed, caused it to be dropped from the list of active ground-to-air missiles in late 1944.

12/ Servo fluid is Visol.

Component Arrangement (See Fig. 18 - SKW 1145C)

The arrangement of the control elements is as follows:

1. A tripropellant steam generator system consisting of:
   a. Mixed acid, Visol, and water tanks
   b. Steam generator
   c. Small pressure bottle, regulator, and firing valve

2. Propellant tanks embodying a new type of swing pipe with flexible bellows rather than a rotary collector. The centrally located propellant lines are abandoned in favor of a series of offset main lines. A point of detailed interest is the arrangement of the propellant-collector goosenecks. The acid collector pipe appears to be well designed, but the line of the Visol tank first leaves the tank and then reenters it. It would probably be simpler and more labor-saving if both tanks had the same construction as the acid tank.

   The final tankage innovation of this version is the use of a single tank with a dividing partition instead of the two tanks previously used.

3. Ignition fluid tank. In place of a propellant control valve assembly this version of the C-2 is provided with a tank of hypergole ignition fluid.

4. Combustion chamber. The combustion chamber contains no control elements and is substantially identical with that previously used.

Operation (See Fig. 18)

Charging of the propellant supply for this version of the Wasserfall involves the handling of no less than four separate propellants. The main propellant tanks receive mixed acid and Visol, while a set of smaller tanks for the steam generator are filled with acid, Visol, and water (coolant). A separate hypergole tank inserted in the fuel line is also loaded. 13/ (All these tanks are sealed at entrance and exit by burst membranes.) After charging the small pressure bottle, the unit is ready for firing.

Unlike the earlier version of this unit, there are no built-in safeties. Once the ground operator fires the cartridge valve (2), the remainder of the operation is automatic and there is no possibility of shutting down.

The pressurized gas is released and reduced in the regulator (4). The damper (21) absorbs the initial surge of pressure. Light burst membranes are blown out and the steam-generator tanks are pressurized. The fuel then blows out the burst membranes (9) located at the head of the steam generator. Visol and acid enter through the injectors in the head of the steam generator and ignite hypergolically. Water flows first through the steam-generator cooling jacket and then into the chamber, where it cools the combustion gas before it enters the main propellant tanks.

The steam pressurizes the tanks and, when approximately 142 psi is reached, the lower burst membranes are penetrated. The acid proceeds directly to the cooling jacket, thence into the injector. The fuel, however, first pressurizes the hypergole in tank (17), which in turn bursts membrane (18) and enters the injector.

The function of the hypergole is to assure a relatively smooth start when the propellants enter the chamber at full-rated flow.

13/ Probably with furfural alcohol, although no reference located specifically stated what was used.

This design reduces controls, in the conventional sense, to the absolute minimum, albeit at the expense of a number of safety features. Only an on-off valve and regulator assembly are present, and the sequencing is assured simply by the arrangement of the elements in a straight line, separated by burst membranes.

Summary and Evaluation of the C-2

The control design for the Wasserfall may be summarized and evaluated in the light of the design requirements. The C-2 missile was intended for almost 100% hits, for which purpose an expensive guidance system was embodied. Consequently, considerable effort was justified in trying to obtain reliable controls for the power plant. The intended manner of use also influenced the controls design; the units were to be factory assembled and stored for considerable periods in "flak centers" until firing. The selection of a constant thrust program and a pressure propellant-feed system simplified the control requirements.

The design of the two versions analyzed above amply meet the specifications. Controls are held to the minimum in both cases. In the first instance (SKW 820C) the operator receives a signal that the missile is armed and ready to fly. In the second (SKW 1145C), there is no arming period but, rather, direct initiation of full thrust. From the standpoint of safety, the operation of SKW 820C may be regarded as less hazardous than that of SKW 1145C.

The following safeties are present in the SKW 820C (Fig. 17) unit:

1. High-pressure release valve
2. Continuous venting of the regulated pressurization circuit before operation
3. Surge damper
4. Positive on-off control by the operator until the high-pressure valve is fired.
5. Slow start and accurate timing assured by the propellant-control valve assembly (See especially the action of the servo-pilot valve.)

SKW 1145C (Fig. 18) has only one safety device, namely, the surge chamber (21). Its application, therefore, demands the use of completely reliable subassemblies. As of February 1945, however, the Germans were not very successful in obtaining reliable components. For example, the action of cartridge valves was unpredictable; the tripropellant steam-generator system proposed in SKW 1145C was not built and tested although evidence showed that it was readily predictable. Hypergolic ignition and swing pipes were both proven design features by the end of the war.

Application to American Practice

The following German design features appear worthy of application to the controls of American power plants having similar requirements:

1. General Arrangement

The extensive use of burst diaphragms for sequencing and control represents a definite forward step in the simplification of manufacture and reduction of cost. Pressure drops may readily be equalized by the proper selection of line sizes and the use of balancing orifices. A reliable cartridge valve offers a light-weight valve and control actuator for the one-time use characteristic of missiles.

2. Detailed Design Features

a. The C-2 regulator assembly(Fig. 19) is excessively heavy and has been surpassed by available American designs. Nevertheless, it contains some excellent components; namely, the high-pressure valve, the 3-way valve, and the surge damper.

b. The general conception and detail design of the propellant control valve are commendable. The valve is not only easy to manufacture but may readily be applies for mixture-ratio control wherever there is no requirement for it to act as a completely tight seal.

c. The hypergole-ignition tank (Fig. 18) is worthy of consideration as a means of improving the start without employing a propellant-timing valve. 14/

d. Although, properly speaking, the steam-generator pressurization is not a control feature, it may be mentioned here as being of considerable interest and possible wide application. It is described in detail in APJ Report No. 51-0-12H (Vol. V), and a comparative evaluation of its application may be found in that report.

BMW P 3390A CONTROL AND SAFETY CIRCUIT

The P 3390A control and safety system displays the problems encountered in a rocket prime mover for piloted aircraft. 15/ The design data for this unit may be summarized according to the general plan of this report.

Design Data

Mission

Function of vehicle using rocket - Rocket interceptor (Me-163)

Function of rocket - Prime mover, also to drive the required aircraft auxiliaries, including generator, cabin supercharger, and hydraulic pump for aircraft landing gear

Installation - One unit mounted in tail. Space envelope and mounting to be completely interchangeable with HWK 109-509

Expected flight attitude - Operation required irrespective of attitude, including steep climb, accelerated flight, and combat maneuvers

Expected ambient temperatures and pressures - -40° to +120°F. Extreme altitude, limited only by aircraft

Safety requirements - The RLM set the following safety requirements:

1. Safe, automatic cutoff if fuel lines break or are punctured
2. Automatic blocking of throttle if the safety circuit or ignition fails to function properly
3. Signal lamps in cockpit to provide visual check of ignition flame, steam generator, and motor operation. Horn signal if turbine overspeeds

14/ A similar expedient was used by Walter in the 109-501 JATO to secure ignition. In this case, however, the hydrazine hydrate was simply poured into the main fuel tank and allowed to sink to the bottom by gravity. This is operationally less reliable than methods selected above.

15/ See APJ Report No. 51-0-12D (Vol. VII), for a discussion of the 109-509 and P 3390C.

4. No start possible in other than prescribed sequence

5. Continuous safety check of engine operation, with automatic shutdown in case of failure

Thrust - The P3390A was to have a maximum sea-level thrust of 3300 lb, infinitely throttlable to to 880 lb by the movement of a simple throttle lever. Click stops were to be provided to indicate the main throttle positions.

Duration - Limited only by tankage; approximately five minutes of powered flight, including cruise

Propellants - Nitric acid and alcohol. Inasmuch as this propellant combination is not hypergole it was necessary to provide an ignition system. The method selected was the use of a hypergole additive. Cooling requirements for the steam generator were to be met by adding water. Thus the P3390A is a 4-propellant unit.

Propellant Feed System - The impulse requirements made the selection of a pump system virtually a necessity. 16/

Ignition and Start - Repeated start was required irrespective of altitude or attitude.

Weight and Space Limitations - As noted above, the space envelope for the P3390A was to conform to that of the HWK 109-509. Weight was to be held to the minimum and the center of gravity was to be as far forward as possible. 17/

Scale of Utilisation - The P3390A was intended for mass production. Indeed, the initial contract for 110 units was let before the design was even begun.

Acceptance Test Requirements - All controls were not only to operate through the range of altitudes, attitudes, and temperatures, but also were to be moistureproof.

Compliance with Aircraft Engineering Standards - Required wherever possible

Delivery Date - The first experimental units were to be running within six months from the letting of the contract. In view of BMW's lack of previous experience with a rocket power plant of this complexity, this was a very severe requirement.

Interrelation of Component Design Factors

Propellant Selection

The anergole propellant selection made it necessary to provide a positive means of ignition. Powder squibs or similar igniters were out of the question because of the need for repeated starts. The means chosen, therefore, was to initiate combustion with a special ignition fluid, Tonka, and when the flame was established, to introduce the main flow of anergoles. Consequently, it was essential that the respective events occur in reliable sequence and that the establishment of a good ignition flame be assured before beginning the full flow of the main propellent. The detail design of the sequence circuit (discussed below) complied with this requirement by positively shutting off the engine if any of the sequence steps failed.

16/ APJ Report No. 51-0-12F (Vol. V) deals with the selection of pump vs. pressure systems.

17/ Because of the RLM's insistence on haste, ultimate refinements and weight savings were sacrificed at a number of points.

Propellant Feed System

The pumps for the propellant feed system are driven by a steam generator-turbine combination. The steam generator, using no less than four propellants - nitric acid, alcohol, Tonka, and a water-alcohol mixture for cooling - is particularly complex. Inasmuch as the coolant mixture must contain at least 40% alcohol to meet the temperature requirement, it might have been simpler merely to add excess alcohol directly than to use an additional cooling pump and controls. However, this would have resulted in a lower energy output per pount of propellant consumption, since the addition of water increased the gas constant, R, of the combustion gas for a given propellant flow. Therefore, more propellant would have to be used for the same horsepower output of the turbine.

Thrust Control

The RLM requirement for infinite control from 880 lb to 3300 lb thrust was responsible for much of the complication of the thrust control circuit.

Installation Requirements

Since the P 3390A and the HWK 109-509 were intended as alternate power plants for installation in the Me-163, complete interchangeability of engines was a requirement. Conventional engine practice suggested the initial selection of a motor-generator for starting. This led to a rather extensive use of electrical controls and probably accounts for the solenoid valves, which had to be energized throughout the run. Experience disclosed, however, that a continuous current drain resulted and only a very limited number of starts could be made with this arrangement. Several alternatives were, therefore, proposed to overcome this defect, including a special electric motor driving a set of three small pumps for starting the steam-generator unit.

Development Time

The RLM delivery date requiring that a prototype engine be available for testing within six months made it necessary to minimize new developments and, so far as possible, to use parts that were in stock. Thus, an electrical control system was preferred to a hydraulic because the subassemblies were readily available. In the end, this procedure seemed to introduce a new difficulty with every attempt to solve a preceding one, and resulted in a cumulative increase of complications. The RLM would certainly have obtained a better engine if they had given BMW a more reasonable development period and had provided a well-thought-out specification.

Metallurgical Requirements

The corrosive properties of nitric acid presented the most serious material problems of the P 3390A. To overcome them, all control system parts which come into contact with the nitric acid were made of aluminum alloy (3-4% Cu) or chrome-nickel stainless steel (V2A extra).

Aluminum and aluminum alloys proved satisfactory for handling alcohol and Tonka; but for parts which would receive extended exposure to any of the propellants, such as the tanks, a special, corrosion-resistant lacquer was recommended as an internal coating.

Various synthetics were tried for seals, gaskets, low-pressure flexible hoses, and valve diaphragms. Dynagen LH 75 (25% Oppanol + 75% Lupolen H) proved most satisfactory. For low-pressure acid, alcohol, and Tonka hoses a combination of Lupolen and Oppanol (trade name, Raspe 37117) was found satisfactory. Buna rubber was used with alcohol and water, but was unacceptable for use with acid.

Standard aircraft electrical parts were employed throughout the safety circuit, and standard aircraft tube fittings were utilized wherever possible.

Design and Operation

The BMW P 3390A rocket engine contains a composite of electrical, hydraulic, and mechanical controls. The main control group is mounted on the engine, and pilot controls and instrumentation are provided in the cockpit. One of the design goals was to have the pilot's controls conform as closely as possible with those of conventional engines.

The detail analysis might best begin with a consideration of the over-all system arrangement and operation. It will then be possible to follow the action of the electrical and safety circuits as they actuate the individual subassemblies.

Component Arrangement (See Fig. 24)

The arrangement of the control system is shown in Fig. 24 which will act as a general reference diagram and guide to the remaining figures. The spatial location of the control elements may be noted in Figs. 27, 28, and 29 which, respectively, give an installation diagram for the control system and photographs of the unit showing many of the assemblies in place.

The following are the P 3390 A control elements:

Part No. (Fig. 24)	Control Part
(1)	Main on-off switch
(2)	Pilot's throttle
(3)	Starter-generator
(4)	Ignition-fluid pumps
(5)	Pressure switches
(6)	Instrument box, including 10 relays and thyrstron tube
(7)	Combustion-chamber controls, including ignition valve, photocell, main cutoff valves, and regulator
(8)	Steam-generator controls, including ignition valve, photocell, cutoff valves, and regulator
(9)	Red and green signal lamps
(10)	Warning horn
(11)	Two 24-volt batteries (aircraft electrical circuit)
(12)	Thrust indicator (chamber-pressure gage)
(13)	Rotary switch

The pilot is provided with a main on-off switch (1) and throttle (2). Instrumentation includes a thrust indicator (12) and two signal lights (9) - red for "ignition" and green for "thrust on." (Fig. 25 includes two additional signal lights: blue to indicate that the electrical control circuit is on, and an auxiliary light (Bl 1) to indicate that the electrical-control thyratron is energized. These were both eliminated in the final version, however, as being unnecessary.) A warning horn (10) is also provided to notify the pilot of turbine overspeed.

An interesting feature is the fact that the pilot's throttle is connected with positive stops in the main rotary switch (located in the main control group). These are sequenced by a solenoid tripper in order to prevent the pilot from throwing the timing out of sequence by going through the throttle-operating range too rapidly. (The blocking-relay mechanism was also eliminated in the final, P 3390C version.)

The construction of the throttle-main-rotary switch subassembly is shown in Fig. 31, which presents a development of the tolerance plan for this unit. Its operation relative to the sequencing is also shown in Fig. 26 and is explained in detail below. Leads from the rotary switch are distributed to the main electrical control elements located in the relay box. (See Fig. 27 for installation, Fig. 30 for detail arrangement, and Fig. 26 for electrical circuit.) Control lines from the relay box run to the starter-generator, ignition pump, steam generator, and combustion chamber.

Pilot's Operating Procedure

From the pilot's standpoint, operation is effected by carrying out the following procedure:

1. Close main switch. (This arms the system.)

2. Move throttle to Position I. In a few seconds the red light goes on and the solenoid tripper reacts and permits the throttle to be moved to Position II.

3. Move throttle to Position II. The red light now goes out. When it is again illuminated Position III is permissible, and then the light goes out again.

4. Move throttle to Position III. Now thrust is obtained and a green light goes on.

5. The pilot may move the throttle forward through Position IV and increase the thrust to the desired value. The green light remains on throughout the operation of the combustion chamber and goes out only when the motor is shut off.

6. The throttle must be returned to Position II before starting again.

Performance and Operating Characteristics (See Fig. 23)

After the airplane has been serviced (the propellant tanks filled and all components checked for proper installation), the tank valves are opened. The propellants - water (steam-generator coolant and servo fluid), acid (oxidizer), and alcohol (fuel) - flow through the pump suction lines through the statically sealed pumps to the two propellant regulators (motor and steam generator). These regulators are normally closed and a by-pass line returns the propellants to the suction side of the respective pumps.

To start the engine the pilot closes the main switch and advances the throttle lever to the start position (Position I), which energizes the motor of the ignition-fluid pumps (acid and Tonka). As soon as the output pressure of the ignition pump reaches approximately 42 psi, the steam-generator ignition valve opens. Tonka and acid enter the chamber and ignite hypergolically. When ignition occurs, the main starter motor is energized, and the gear train and three main pumps start to rotate. The propellants are pumped to the regulators and recirculated to the pump suction. A portion of each propellant is by-passed from the pump discharge to jet pumps in the suction lines. These increase the suction pressure and prevent pump cavitation. (See APJ Report No. 51-0-12G, Vol. V.)

When the main propellants reach 14 psig, if the ignition flame is still burning, the steam-generator regulator is opened. The propellant-pump discharge pressures have now increased to the idling value; acid and alcohol flow directly into the steam generator and ignite from the ignition flame. Simultaneously, water flows from the regulator valve through a throttle control and chamber jacket into the steam generator. (See APJ Report No. 51-0-12E, Vol. V.) As soon as the steam reaches a pressure of 128 psi, the ignition fluid pumps and valve are automatically shut off.

The starter-generator motor is now driven by the turbine and acts as a generator for the remainder of the rocket operation. The pilot receives a lamp signal when the steam pressure reaches 210 psi and he may now move the throttle to the next position (Position II).

The igniter fluid pumps are again started and a similar ignition procedure takes place for the rocket motor. As soon as combustion at idling thrust is sustained, the ignition pumps and the ignition valve are shut off (Position III).

The thrust may now be varied at will from 880 lb to 3300 lb by moving the throttle, which is directly connected by linkage to the steam-generator and combustion-regulator servos (Position IV). Movement of the throttle changes the pintle-valve positions in the regulators and meters the proper amount of propellants to the respective chambers. The two regulators are interconnected, so that proper matching of the turbine speed and the pump outputs is secured for each thrust setting.

Combustion may be terminated at any time if the throttle lever is retarded beyond the idling-thrust position. Restart in flight is possible by a repetition of the starting procedure.

Electrical and Safety Circuit

The elements whose operation is described above are sequenced and actuated by electrical controls. The requirements set up made it necessary that accurate sequencing of each step in the operation be adhered to, with a system of positive safeties to assure that the unit would shut down if any step failed. This was accomplished by the system of relays set up in the relay box and electrically sequenced by movement of the rotary switch. All sequencing, therefore, is correlated with the positions of the throttle and, through it, with the rotary switch settings.

The operation of the electric and safety circuit may be followed from Fig. 26. (The relays are denoted by capital letters while the contacts belonging to them have the corresponding small letters. In order to make the circuit easier to follow, the contacts and their corresponding relay coils are shown separated, with the contacts in positions at which there is no current in the relays. The small table attached to Fig. 26 shows the relationship between the setting of the pilot's throttle and the position of the contacts s_0 through s_5 of the rotary switch.)

Three solenoid-operated latches on the rotary switch assembly prevent advancement of the throttle lever until the proper safety checks have been made. The location of these latches is shown on line M in the small sketch on Fig. 26. A single solenoid (M) makes all three settings in the manner explained below. The table on Fig. 26 also shows the relationship between the throttle setting and thrust. Idling thrust (880 lb) starts between Positions III and IV, and then increases from 880 lb to 3300 lb.

Throttle Position 0 - Arming

Operation is begun by the pilot, who closes switches T1 and T2. (See Fig. 25.) This arms the system and permits current to heat up the thryatron.

Throttle Position I - Test Circuit and Steam-Generator Start

Relays P, A, C, and B (left side of Fig. 26) form the test group whose purpose it is to check the operation of the thyratron and the insulation of the photocell circuits and then to switch on the ignition-fluid pump motor. Relay C', which switches on the igniter-fluid pump, is mounted near this motor, since it was not deemed desirable to carry the high-operating currents to the instrument box. C' could be eliminated if the current were brought into the box and two extra contacts added to relay C; however, this would add weight, complexity, and battery drain.

The closing of switch s_0 permits current to flow through switches c_1, b_3, and p_1, energizing relay P, which operates the check circuit for the photocells and thyratron. The action of relay P is delayed by the time required to load the condenser placed in parallel with it. After the condenser is charged, relay P fires, opening switch p_1 and closing switch p_2. But when p_1 returns to its open position it again energizes P, causing the cycle to repeat. The closing of switch p_2 energizes relay A, which actuates switch a_1. This permits current to flow into the self-locking relay B. Consideration of the operation of relay P discloses that, after it is energized, it cuts itself off by opening switch p_1; hence, cutting out relay A after the delay imposed by the condenser. However, during this interim, A has already performed its mission in energizing solenoid B, which provides the first completely locked-in circuit in the sequence.

When B is energized, it not only closes switch b_1, providing itself with an energy source, but also closes switch b_2, providing a path for the current to both relay C (switch a_1 automatically opens when relay A falls out) and relay C', which energizes the ignition-fluid motor and the main starting motor. The third function of relay B is to open switch b_3, shutting off the check circuit. This relay arrangement assures the satisfactory operation of the check circuit before permitting the self-locking relays B and C to operate. The closing of relay C also closes switch c_2, which energizes the coil of relay E, closing switch e_1. However, no current can flow through this branch of the line until pressure switches DZ close. The rocket engine may now start.

As soon as the ignition fluids (acid and Tonka) have reached the proper pressure, both pressure switches DZ are actuated and the solenoid-controlled ignition valve ZV1 of the steam generator, opens. The current flows from c_1 to DZ, to u_2, and to ZV1. As soon as ignition occurs, photocell Ph1 becomes conducting, the thyratron ignites again, and relay A opens. E remains locked in by means of its holding coil even when the ignition flame goes out.

The main turbine-pump unit is rotated by the starter motor. Contact a_1 closes and the current flows to c_2, to u_3, and to E. Contact c_1 also closes and the current flows to DZ, to u_2, to e_1, and finally to E.

When the propellants reach a pressure of 14 psi, pressure switch DH closes. The main valve HV1 then opens if the ignition flame is burning (the photocell is in the circuit). Simultaneously, the holding relay H is energized and remains so with the aid of h_1. This holds the main valve HV1 open, and cuts off photocell Ph1. Relay A then drops out. The current flows through the closed contacts a_1 and c_2 to u_3, to DH, to H, and to HV1. Current also flows through the closed contact h_1 to DH and to H.

As soon as the propellant pressure reaches 128 psi, pressure switch DU is actuated. The test group then cuts out, and the ignition pump motor and the starter are turned off. The turbine-pump unit is now powered by the steam generator. As the pump speed increases, the starter-generator serves as a generator and produces current. This current activates the blocking solenoid M at the rotary switch and, simultaneously, the red signal lamp in the pilot's cabin lights up. This is a signal to the pilot that the throttle can now be moved forward.

<u>Throttle Position II - Combustion-Chamber Ignition</u>

When the pilot pushes the throttle to Position II, cam switches s_2, s_3, and s_4 are closed. The change-over relay U is energized and reactivates the test group through contact u_1. Once again, as during the starting of the steam generator, the thyratron and the photocell Ph2 are tested. The ignition-pump motor is also started again.

As soon as the Tonka and acid have reached the proper pressure, the ignition valve ZV2 of the combustion chamber is opened. The current flows through the closed contact c_1, through DZ, to u_2 (closed), and to ZV2. Ignition occurs and relay A again responds. The blocking solenoid M is energized and the red lamp in the cockpit again lights. Since the red lamp lights and goes out with the action of the ignition circuit, the pilot can continually check operation. Current flows through the closed contacts a_1, to c_2, to u_3, to s_2, to M, and to the red lamp (rt).

Throttle Position III - Idling Thrust (880 lb)

The pilot can now move the throttle to Position III, and contact s_5 closes. As soon as ignition takes place, the main combustion-chamber valve HV2 opens and is held open by relay J through contact i_1. The green lamp in the pilot's cockpit lights up, indicating combustion. Simultaneously, the blocking solenoid M releases the throttle so that it can be advanced. (The current flows through the closed contacts a_1 and c_2, to u_3, to s_5 (closed), to J, to HV2, and to the green lamp (gr). It also flows through the closed contacts i_1 and s_5 to J.) Idling thrust (880 lb) is now obtained.

Throttle Position IV - Main Operatin Range

If the pilot advances the throttle lever farther, only rotary contacts s_0 and s_5'remain energized, and only the main valves HV1 and HV2 remain'on. Both the test group and the ignition-fluid-pump motor are turned off.

If the pilot should move the throttle back to Position III and later wish to increase thrust again, he needs merely to return to Position IV at any time as long as the combustion chamber continues to operate. If the throttle has been pulled back slightly farther than Position III, the combustion chamber is cut off by switch s_5. Then the throttle becomes blocked between Positions II and III, the main valve HV2 remains closed, and the pilot must return his throttle to Position II to restart.

When the throttle is pulled back to Position II (start of combustion chamber) the change-over relay U is energized again through the switch s_3. This again energizes the test group as described above, and the ignition of the combustion chamber restarts.

If the pilot returns the throttle to Position 0, the entire rocket engine is immediately shut off, but the thyratron is continuously heated until switch T2 is opened. This prevents delays in restarting.

Safety Features

The safety measures of the P 3390A operated as follows:

1. If one of the main propellants fails, one of the pressure switches DH is interrupted, and relay H cuts out. This causes contact h_2 to return to normal position, which discharges the attached condenser through F and causes F to respond by shutting off the rocket engine. F is held in this position by means of f_1. The engine can then be restarted only if the main switch T1 is pulled or the throttle is returned to Position 0. The operation of the safety relay F, placed in the circuit as shown in Fig. 26, results in an immediate closing of the main valves of the combustion chamber before shutdown of the turbine pump unit. This produces water hammer and may result in a failure of the inner jacket of the combustion chamber as well as pipe lines. Relay F was later placed in the circuit in such amnner that the steam generater valves closed before the combustion chamber valves. Water hammer was thus eliminated at shutoff.

2. In the event that the turbine overspeeds, the pressure switch DW closes and warns the pilot by means of the horn W. He should then shut down his engine. The use of only one pressure switch, however, is not reliable, since one of the other two propellant feed lines might fail and the turbine would overspeed without warning the pilot.

Operation Summary

The operating sequency described above is summarized in tabular form to aid in a review of the system function. (See Table 4.)

Table 4

Operation Summary of BMW P 3390A Electrical and Safety Circuit

Activity	Component	Contacts	Operation	Function
Start of Steam Generator	Throttle Position 0	Switch T1	Closed by pilot	Arms system. Heats thyratron
Check Circuit	Throttle Position 1	s_0, s_1	Rotary switch moved by throttle	Check circuit energized
	Relay P	p_1, p_2	Oscillating from contact p_1	Energizes relay A
	Relay A	a_1	Oscillating from contact p_2	Energizes relay B
	Relay B	b_1, b_2, b_3	Self-locking through contact b_1	Energizes relay C & C'. Cuts off test circuit P and A
Ignition	Relay C	c_1 & c_2	Self-locking through contact c_1	Energizes relay E and holds in relay C
	Relay C'	-	Locked in by relay C	Energizes motor of the ignition fluid pumps ZM and starter (Anl.)
	Pressure switches DZ	-	Closed by ignition fluid pressures	Permits current to open ignition valve ZV1 of steam generator
	Ignition valve ZV1	-	Energized when pressure switches DZ close through c_1. DZ, u_2	Allows Tonka and acid to enter steam generator and ignite
Start	Photocell Phl	-	Activated by ignition flame	Indicators ignition through relays P and A
	Pressure switches DH	-	Circuit closed when all 3 propellants reach at least 14 psi	Energizes relay H. Opens main steam generator valve
	Relay H	h_1	Energized when 3 DH pressure switches close	Closes contact h_1, cuts out photocell Phl, and holds HV1 open

Table 4 (Cont'd)
Operation Summary of BMW P 3390A Electrical and Safety Circuit

Activity	Component	Contacts	Operation	Function
	Valve HV1	-	Opened when DH pressure switches close through b_1, c_2, u_3, DH	Allows propellants to enter steam generator and start combustion
	Pressure switch DU	-	Opens when main propellant pressures reach 128 psi	Cuts out check group, including ignition pump and starter motor
	Starter generator	-	Driven through overriding gear by turbine	Generates current and activates blocking solenoid M and red signal lamp
	M	-	Activated by generator through s_1	Allows pilot to move throttle to Position II
Start of Combustion Chamber	Throttle Position II	s_0, s_2, s_3, s_4	Rotary switch moved by throttle	Activates relay U
	Relay U	u_1, u_2, u_3	Activated through contact s_3	Activates contacts u_1, u_2 and u_3, and current flows to check group through u_1
Check Circuit	Same as for steam generator. Thyratron and photocell Ph2 checked			
Ignition	Relay C	c_1, c_2	Self-locking through contact c_1	Holds in relay C'
	Relay C'	-	Locked in by relay C	Energizes the motor of the ignition fluid pumps
	Pressure switches DZ	-	Closed by ignition fluid pressures	Opens ignition valve ZV2 through c_2 and u_2
	Ignition valve ZV2	-	Opened through c_1, DZ, u_2	Allows Tonka and acid to enter motor and ignite
Operation	Photocell Ph2	-	Activated by ignition flame	Indicates ignition through relays P and A, and energizes blocking solenoid M and red lamp
	M	-	Activated by check circuit through a_1, c_2, u_3, s_2	Allows throttle to be moved to Position III and lights red lamp in cockpit

Table 4 (Cont'd)
Operation Summary of BMW P 3390A Electrical and Safety Circuit

Activity	Component	Contacts	Operation	Function
	Throttle Position III	s_0, s_2, s_4, s_5	Rotary switch moved by throttle	Activates relay, opens main chamber valve HV2, and lights green lamp
	Relay J	i_1	Activated through contact s_5	Closes contact i_1, holds HV2 open, and energizes solenoid M
	Valve HV2	-	Opened through contact s_5	Allows propellants to enter combustion chamber and start combustion
	Solenoid M	-	Activated through i_1, s_2	Allows throttle to be moved to Position IV. Thrust is now 880 lb
Operation	Throttle Position IV	s_0, s_5	Rotary switch moved by throttle	Cuts out check circuit and ignition fluid pumps. Only valves HV1 and HV2 are on. Thrust may be increased from 880 lb - 3300 lb

Summary and Evaluation of the BMW P 3390A

The system described was a major step in the BMW development of an aircraft prime mover. Numerous proposals preceded it and a large number of detailed changes were made in the course of its development. Some of the trouble spots that were modified were the excessive instrumentation and the substitution of chamber-pressure switches for the photocells and thyratron. This was a desirable change, since the photocells and thyratron were the cause of frequent system failure. They also required excessive electrical relays and wiring to insure proper insulation and functioning.

Similarly, flight-test reports from experience obtained with the HWK 109-509 engine in the Me-163 disclosed that the drain of starting the motor was so great as to limit severely the number of air-borne restarts. This condition was most undesirable, since the Me-163 flight program contemplated short bursts of power, punctuated by glides.

Accordingly, BMW later installed a special electric motor which operated a new set of three pumps. These were intended for starting the steam generator and for producing enough steam to start the turbine pump units. The starter-generator was eliminated and a simple generator was used instead.

The recital of these changes indicates the number of modifications in the control system that were brought about by experience. Indeed, the lessons learned in the course of the P 3390A development were very helpful to BMW to the extent that some of the P 3390A subassemblies were directly applied in succeeding projects, such as the P 3395 and P 3390C. 18/

18/ The development sequence of the P 3390C controls is discussed in APJ Report No. 51-0-12D, (Vol. VII).

The P 3390A control must be considered in the light of the time limitations under which BMW worked and the initial set of control requirements. Both the RLM had only sketchy experience with rocket engines as applied to piloted aircraft. They were, therefore, very conservative about component reliability and specified a complete safety circuit, characterized by a step-by-step sequencing arrangement. Their approach was to design a set of control subassemblies and tie them together by means of stringent safety control, rather than by making use of such factors as line drops, etc. This attitude is in contrast with that used by Peenemunde and Walter.

Working under severe time pressure, BMW felt it desirable to develop the P 3390A in the manner described above because it permitted the maximum degree of simultaneous component development. Thus, it was the responsibility of each design group to produce its subassemblies without waiting for the operating characteristics of the concomitant subassemblies to be accurately determined. The influence of the time pressure is also evident in such detail design as the selection of an electrical control, which used stock parts, instead of a hydraulic control, which would need development. When difficulties arose, they were solved by the addition of components rather than by a reconsideration of the basic design.

As experience accumulated, BMW gradually overcome these handicaps and progressed toward improved systems. For example, the control of the P 3390C went through no less than 11 different versions, each one resulting in a progressive simplification and a gradual elimination of components. In the end, they evolved a system using only a minimum of hydraulic servos, and they practically eliminated electrical controls. The excessively complicated system of propellants was also gradually simplified by shifting from an anergole to a hypergole combination, which made feasible the elimination of the ignition circuit.

Application to American Practice

While the direct application of the P 3390A control system to American rocket development is not recommended, there are some lessons worthy of observation:

1. The need for drawing up a well-thought-out specification and carefully examining it to eliminate inconsistencies and redundant requirements is apparent.

2. The specification should be reviewed periodically during the development to assure that it makes best use of available technology. Thus, as subassemblies become more reliable, it becomes possible gradually to simplify the safety and operational checking circuit.

3. The individual control elements must be considered with close attention to the design requirements.

4. The ignition problem attacked in the P 3390A is not dissimilar from that currently encountered in American work with nitric acid and gasoline, and BMW experience in this regard seems directly applicable. The idea of using a liquid hypergole additive for igniting the anergole must be tested by experience. Nevertheless, it remains one of the means which reliably worked in practice. In this respect, the P 3390A control system is worthy of study, and the utilization of this experience may be expected to save both time and cost in American practics.

BIBLIOGRAPHICAL REFERENCES

	AUTHOR(S)		ORDER NO.
[1]	Dellmeier	Starthilfe B 8 (1000 kg) Stand der Entwicklung (Jato, Type B 8 (1000 kg) State of Development as of December 1939) F.E. 572 Dec 1939 APJ No. A 9-30 Not available from CADO	
[2]		Technischer Breifwechsel betreffend die Entwicklung von Starthilfen und Raketenantrieb durch HVP Peenemuende (Technical Correspondence Concerning the Development of Jatos and Rocket Meters as Carried out by HVP - Peenemuende) Peenemuende 1935-1941 APJ No. A 9-49 Not available from CADO	
[3]	Thiel	Bericht ueber die Entwicklungsarbeiten auf dem Triebwerkgebiet (Summary of Rocket Power Plant Work) F.E. 343 1940 APJ No. A 13-29 Not available from CADO	
[4]	Dellmeier	Betriebshandbuch fuer Geraet RI 101b (Operating Manual for Jato RI 101B) Archive 70/3 April 1942 APJ No. A 9-53 Available from CADO as original language only	PGM 25
[5]	Dellmeier	Aktenvermerk vom 29.5.40 ueber HVP-Rauchgeraet B 8 (Document Annotation on HVP-Rocket B 8 from May 1940) CGD 694-30.1 Archive 70/2 APJ No. A 9-70 Available from CADO as original language only	PGM 25
[6]	Bernd	Stand er Serienreifmachung der R-Geraete (Description of Rocket Motors G 1 and B 8) Bodenbach, Wilhelm Schmidding July 1941 APJ No. F 9-188 Available from CADO as original language only	SC/294/Re/294 R 3344 F 435

BIBILOGRAPHICAL REFERENCES (Cont'd)

	AUTHOR(S)		ORDER NO.
[7]		Schmidding Documents Captured in Cologne (In English) APJ No. F 13-127	
		Available from CADO	CGD 161
[8]	Bernd	Stand der Serienreifmachung der R-Geraete (Status of Preparation for Mass Production of the Rocket. Comparison of G-1 B-8a) Wilhelm Schmidding Bodenbach APJ No. F 13-131	
		Available from CADO as original language only	SC/167/167 R 2435 F 942
[9]	Bernd	Stand der Serienreifmachung der R-Geraete (Description of Rocket Motors G-1 and B-8a) Bodenbach, Wilhelm Schmidding July 1941 APJ No. F 9-188	
		Available from CADO as original language only	SC/294/Re/294 R 3344 F 435
[10]		Schmidding Documents Captured in Cologne (In English) CGD 161 APJ No. F 13-127	
		Available from CADO as Translation only	CGD 161
[11]	Bernd	Arbeitsbericht fuer den Monat Februar ueber den Stand der Versuche und der Entwicklung in der R-Abtailung (Monthly Report on the Condition of Test and Development of Rocket Motors) Bodenbach, Wilhelm Schmidding Feb 1941 APJ No. F 13-128	
		Available from CADO as original language only	SC/295/Re/295 R 3335 F 1028
[12]	Bernd	Stand der Serienreifmachung der R-Geraete (Status of Preparation for Mass Production of the Rocket. Comparison of G-1 and B-8a) Wilhelm Schmidding, Bodenbach APJ No. F 13-131	
		Available from CADO as original language only	SC/167/167 R 2435 F 942

BIBLIOGRAPHICAL REFERENCES (Cont'd)

	AUTHOR(S)		ORDER NO.
[13]	Perlchen	Ueber den Niederschlag von Feuchtigkeit in Druckminderern (Condensation of Moisture in Pressure Reduction Valves) Karlschagn Mar 1944 APJ No. A 5-4	
		Available from CADO as original language and translation	ATI 32537
[14]	Haase	Abstimung von "Wasserfall" Versuchsgeraeten (Determination of the Mixing Ratio for the Missile "Wasserfall") Archive 66/18 March 1944 APJ No. A 5-5	
		Available from CADO as original language only	PGM 25
[15]		General Notes on Valves of Various Types and Bursting Diaphragms for C-2. Development Data F.E. 1779/5 APJ No. A 5-23	
		Not available from CADO	
[16]	Heller	Unterlagen fuer Triebwerk des Projektes C-2 (Basic Considerations for the Propulsion Unit of the "Wasserfall" Missile) HVP Feb 1943 APJ No. A 9-37	
		Available from CADO as original language only	PGM 34
[17]		Propulsion System of the "Wasserfall" Heeres Versuchssanstalt Peenemuende 1944 APJ No. A 9-39	
		Not available from CADO	
[18]		Fliegwerkstoff-Handbuch (Handbook on Aircraft Construction Materials) RLM Technisches Amt. July 1943 APJ No. A 20-13	
		Not available from CADO	

BIBLIOGRAPHICAL REFERENCES (Cont'd)

	AUTHOR(S)		ORDER NO.
[19]		Beschreibung des Sicherungsgeraetes fuer die Anlage P 3390 A (Description of the Safety Device (Automatic Regulator) for the Power Unit P 3390 A BMW (Rocket)) Bayerische Motoren Werke June 1943 APJ No. F 5-7	
		Available from CADO as original language only	BMW/R/Re/U 85 R 2135 F 736
[20]		Sicherheots-Einrichtung (Safety Control Device for P 3390 A Rocket) Bayerische Motoren Werke Sept 1942 APJ No. F 5-36	
		Available from CADO as original language only	BMW/R/Re /77 R 2137 F 220
[21]	Hoffmeister	Beschreibung einer Scherungsanlage fuer das Geraet P 3390 A (Electrical Control Mechanism for Rocket Motor P 3390 A) Berlin-Spandau, BMW Flugmotorenbau G.m.b.H. Dec 1942 APJ No. F 5-68	
		Available from CADO as original language only	BMW/EZR/5/4/42 R 3306 F 1052
[22]		Betractungen ueber Betriebssicherheit (Description and Evaluation of a Safety Device for the P 3390 A Rocket Unit) Spandau, BMW Flugmotorenbau G.m.b.H. Nov 1941 APJ No. F 5-78	
		Available from CADO as Original language only	BMW/MA-AKT-41 R 8038 F 452
[23]		BMW Bezeichnung P 3390 A - am 23.11.42 (Development of R II 303-BMW Destination P 3390 A Rocket Unit) Spandau, BMW Flugmotorenbau G.m.b.H. Nov 1942 APJ No. F 9-41	
		Available from CADO as original language only	BMW/ERF/A/150-42 R 4066 F 390-407

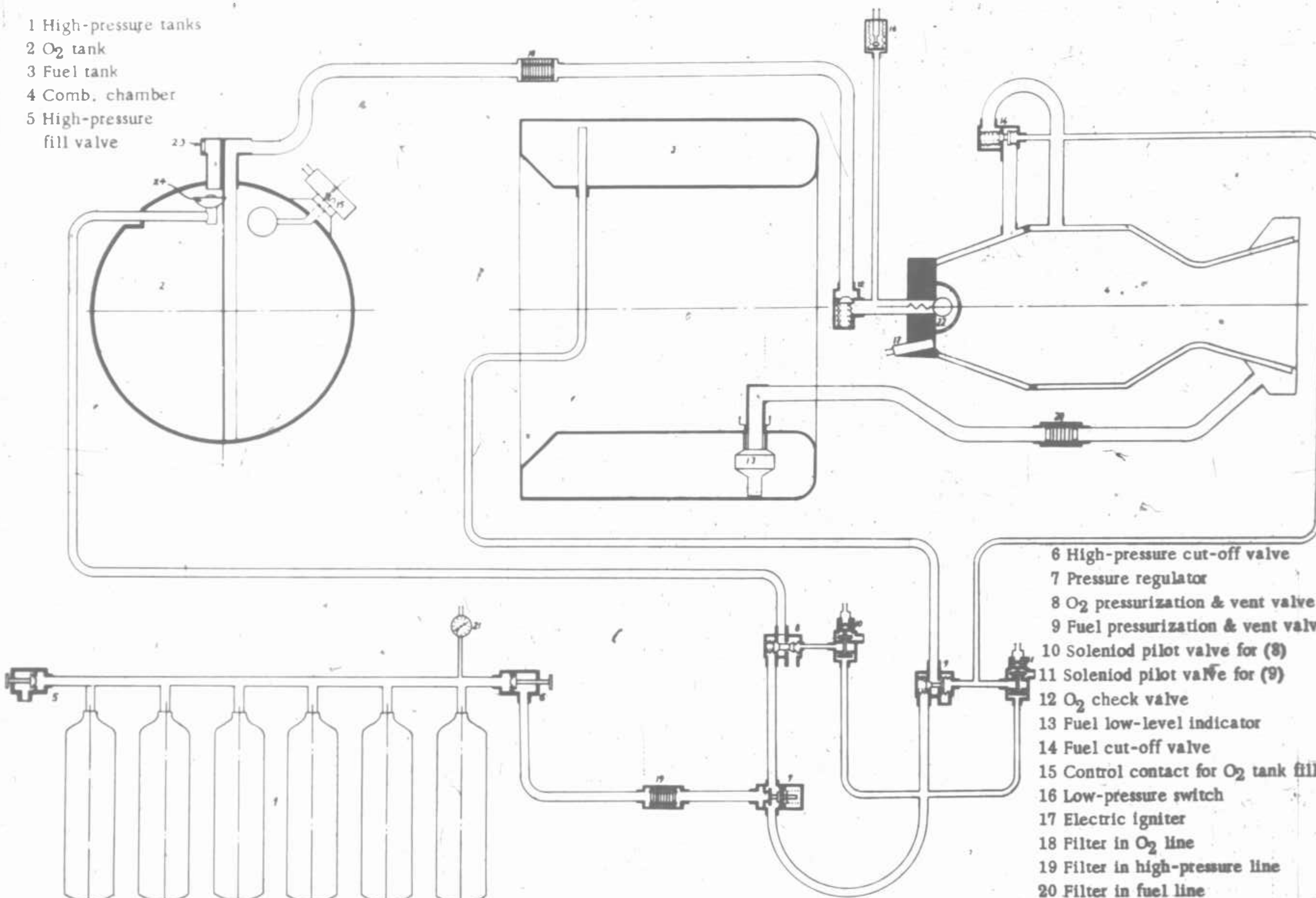
BIBLIOGRAPHICAL REFERENCES (Cont'd)

	AUTHOR(S)		ORDER NO.
[24]	Schneider	DFS 228 (Installation of P 3390 A Rocket Motor in DFS 228, Experimental Extreme Reconn. Aircraft) Spandau, BMW Flugmotor-enbau G.m.b.H. April 1943 APJ No. F 9-206	
		Available from CADO as original language only	BMW/R/NDS/214/43 R 2661 F 635
[25]		Verentwicklungsarbeiten zum Geraet P 3390 A (Report on the Development of the Rocket Unit P 3390 A) Muenchen, BMW Flugmotorenbau June 1943 APJ No. F 13-37	
		Available from CADO as original language only	BMW/R/U 106 R 2449 F 676
[26]	Emrich	Das Verhalten von Dynagenprodukten gegen Oxydatoren (Resistance of "Dynagen" Products to Oxidizing Liquids) Muenchen, BMW Flugmotorenbau April 1943 APJ No. F 20-1	
		Available from CADO as original language only	BMW/EZV/387/43 R 2390 F 369
[27]	Hemesath	Dichtwerkstoffe Oppanol - Lupolen (Oppanol and its Combinations as Nitric-Acid Proof Packing Material) Spandau, BMW Flugmotorenbau G.m.b.H. June 1943 APJ No. F 20-15	
		Available from CADO as original language only	BMW/R/- U 137 R 2411 F 297
[28]	Brunnthaler	Erprobung von Gummiersatzwerkstoff Bu 4207a (Test of Synthetic Rubber Bu 4207a for Bushings and Grommets) Muenchen, BMW Flugmotorenbau G.m.b.H. May 1942, APJ No. 20-25	
		Available from CADO as original language only	BMW/ET/745/021 R 3283 F 419

BIBLIOGRAPHICAL REFERENCES (Cont'd)

AUTHOR(S)		ORDER NO.
[29] Wessel	Korrosionsbestaendige Staehle (Nitric-Acid Resistant Steel Alloys) June 1943 APJ No. F 20-26 Available from CADO as original language only	BMW/ERK- Mit-312/43 R 3689 F 820

ILLUSTRATION REFERENCES



1 High-pressure tanks
2 O_2 tank
3 Fuel tank
4 Comb. chamber
5 High-pressure fill valve

6 High-pressure cut-off valve
7 Pressure regulator
8 O_2 pressurization & vent valve
9 Fuel pressurization & vent valve
10 Soleniod pilot valve for (8)
11 Soleniod pilot valve for (9)
12 O_2 check valve
13 Fuel low-level indicator
14 Fuel cut-off valve
15 Control contact for O_2 tank filling
16 Low-pressure switch
17 Electric igniter
18 Filter in O_2 line
19 Filter in high-pressure line
20 Filter in fuel line
21 High-pressure manometer
22 O_2 injector with check valve
23 Lox tank safety burst-diaphgram and fill valve
24 N_2 diffussor in lox tank

Fig. 1 - Schematic Flow Diagram-B7

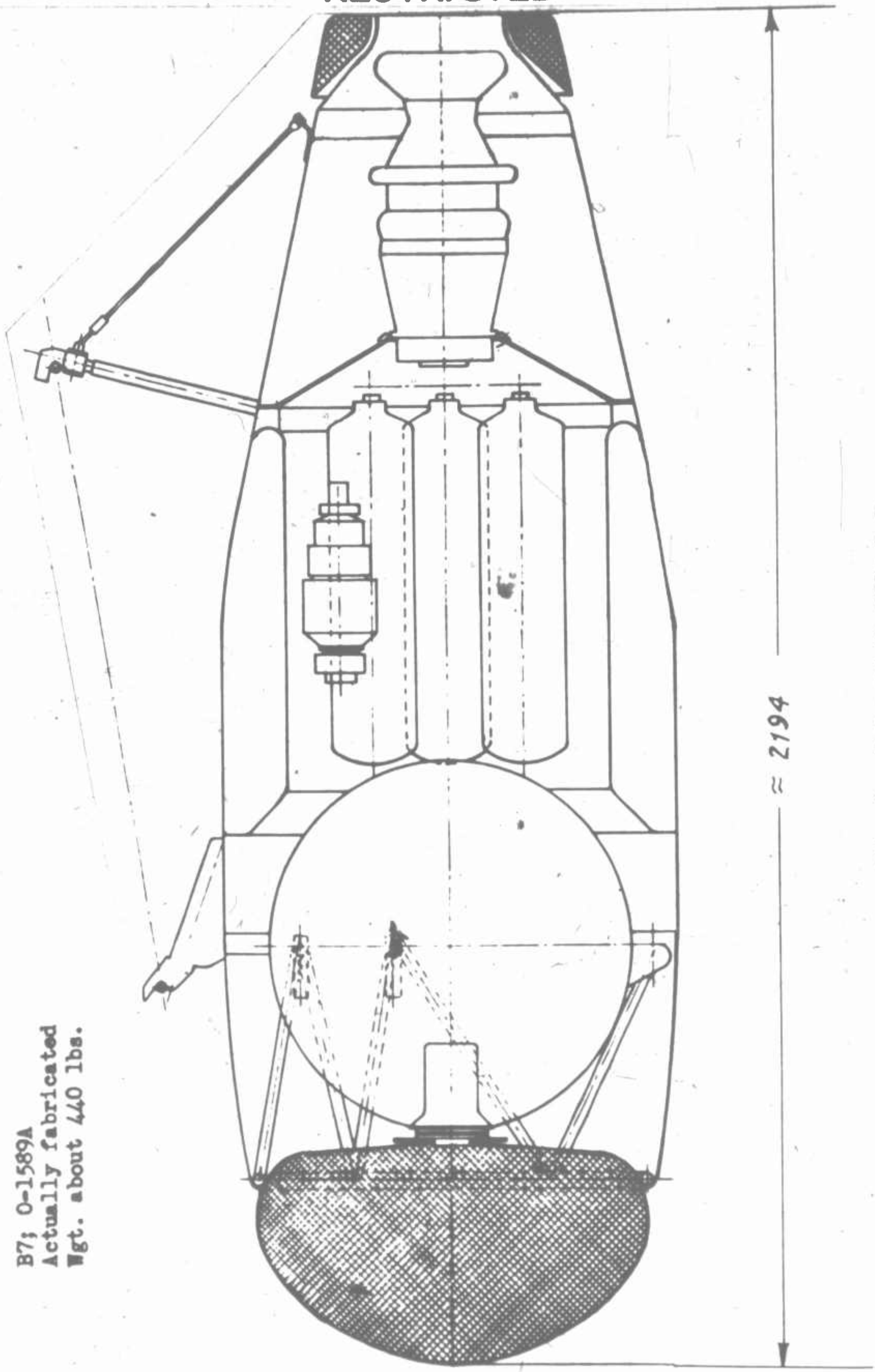


Fig. 2 - Inboard Profile B-7

B-8 Components

1. High-pressure nitrogen tanks
2. High-pressure hand on-off valve
3. Pressure regulator
4. Burst-diaphragm valve
5. Solenoid pilot valve
6. "T" pipe connection
7. 3-way ball-check valve
8. Nitrogen impact plate
9. Liquid-oxygen injector
10. Alcohol combustion cutoff valve
11. Liquid-oxygen pressure switch
12. Relay and contact
13. Residual-fuel indicator
14. Double solenoid valves
15. Fuel-tank vent valve
16. Liquid-oxygen tank-fill indicator

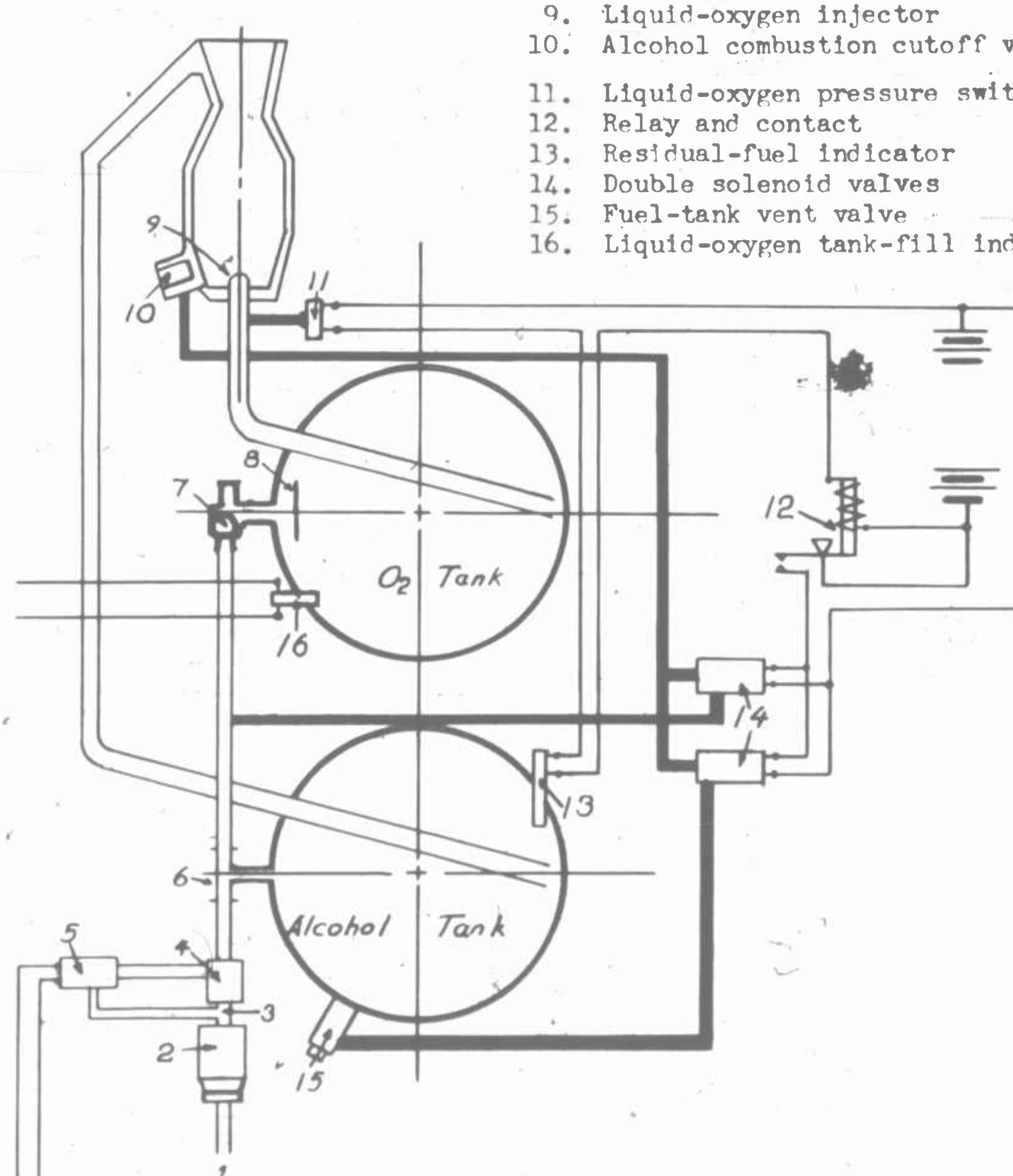


Fig. 3 - Control Schematic - B-8

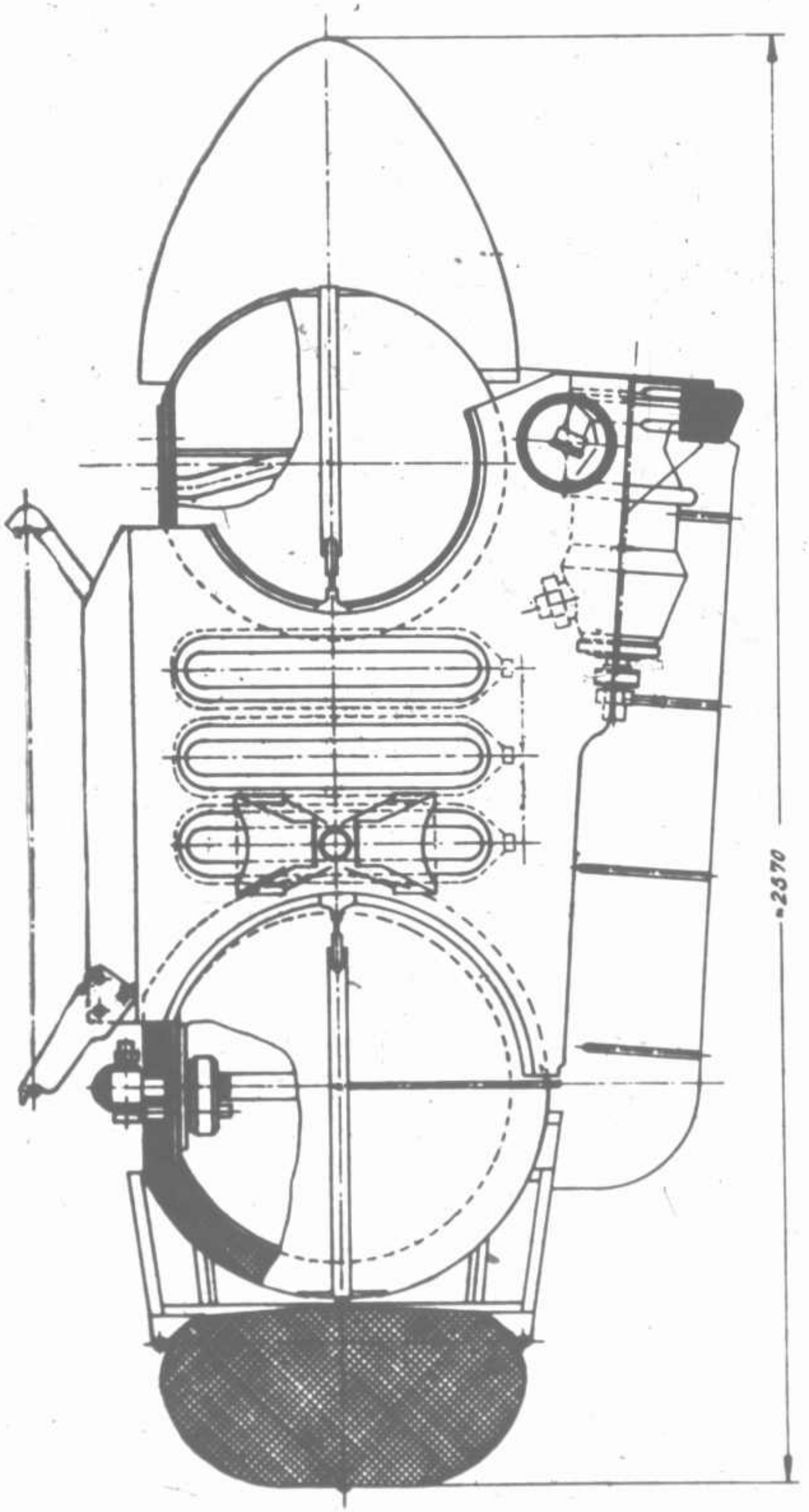
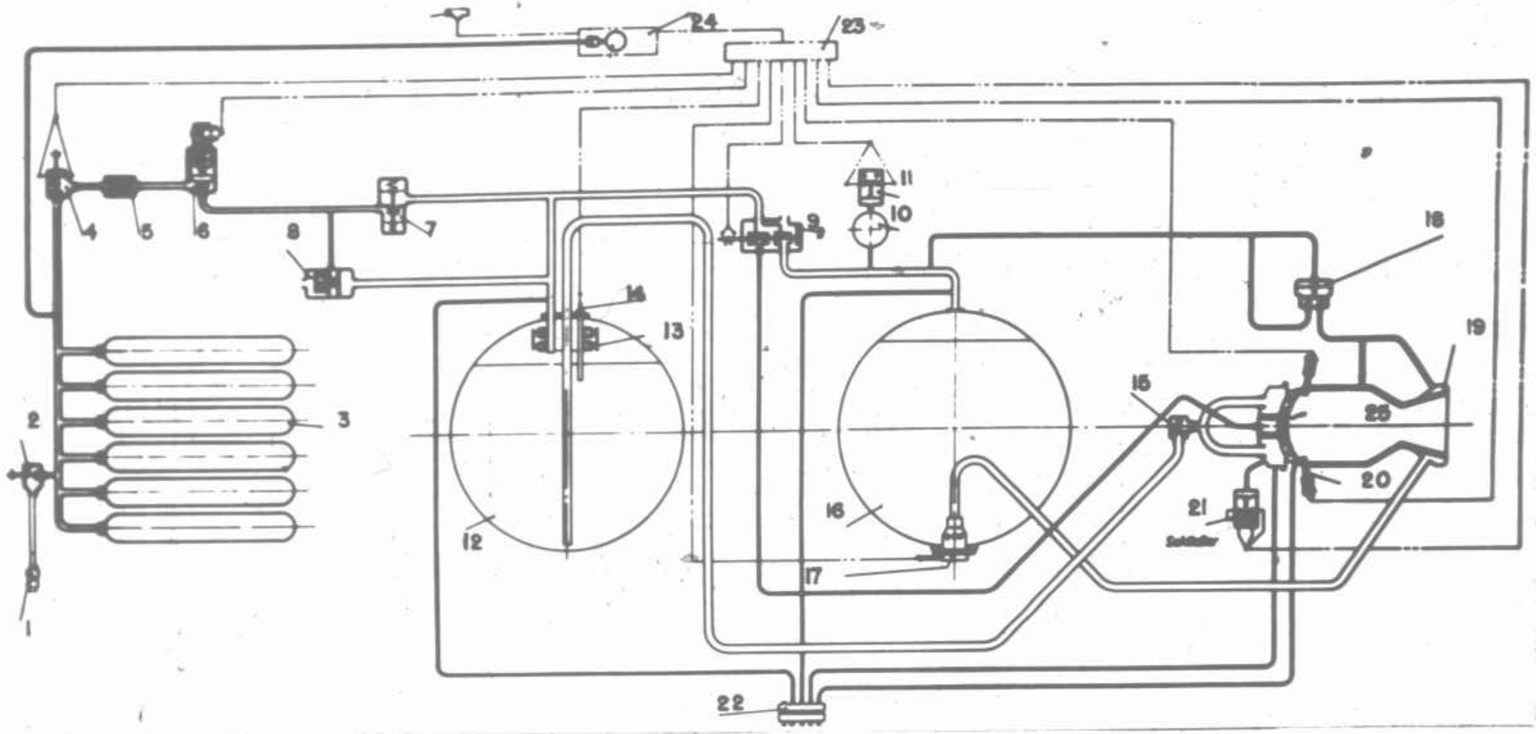


Fig. 4 - Inboard Profile - B-8

B8; O-2100 A
Actually fabicated
Wgt. without parachute
about 363 lbs.



	B-8a (RI-101b) Components	
1.	Quick coupling attachment	13097L
2.	Hand-operated fill valve	207 E
3.	High-pressure nitrogen tanks	--
4.	Hand valve with electric contact	2975E
5.	Filter	DBU FR13A
6.	Solenoid-operated on-off valve	--
7.	Pressure regulator	2074C
8.	Controlled vent valve	1991D
9.	Four-way valve	2736E
10.	Damping chamber	2974E
11.	Pressure switch	2605E
12.	Liquid-oxygen tank	1400C
13.	Jet diffuser	2683D

	B-8a (RI-101b) Components	
14.	Liquid-oxygen tank-fill gage	2090D
15.	Liquid-oxygen check valve	1417E Aust.B
16.	Alcohol tank	2707C
17.	Alcohol-flow indicator	15078/4
18.	Chamber-jacket vent valve	2765E
19.	Combustion chamber	3026B
20.	Igniters	1600D
21.	Pressure switch	2605E
22.	Pressure manifold	E13096-21
23.	Junction box	
24.	Pressure gage	
25.	Fuel cutoff valve	

Fig. 5 - B-8a Control Schematic

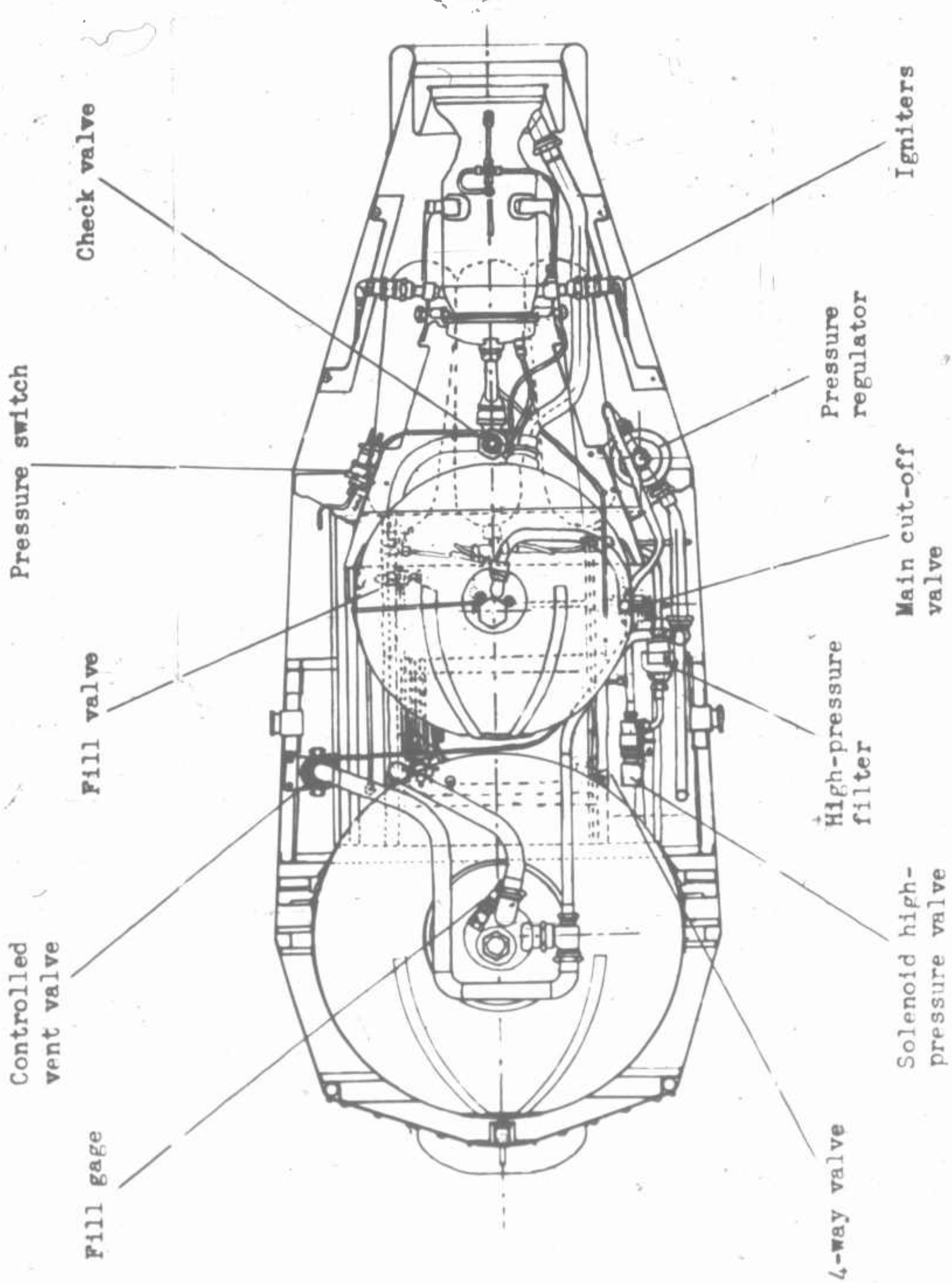


Fig. 6 - JATO RI-101B - Top View

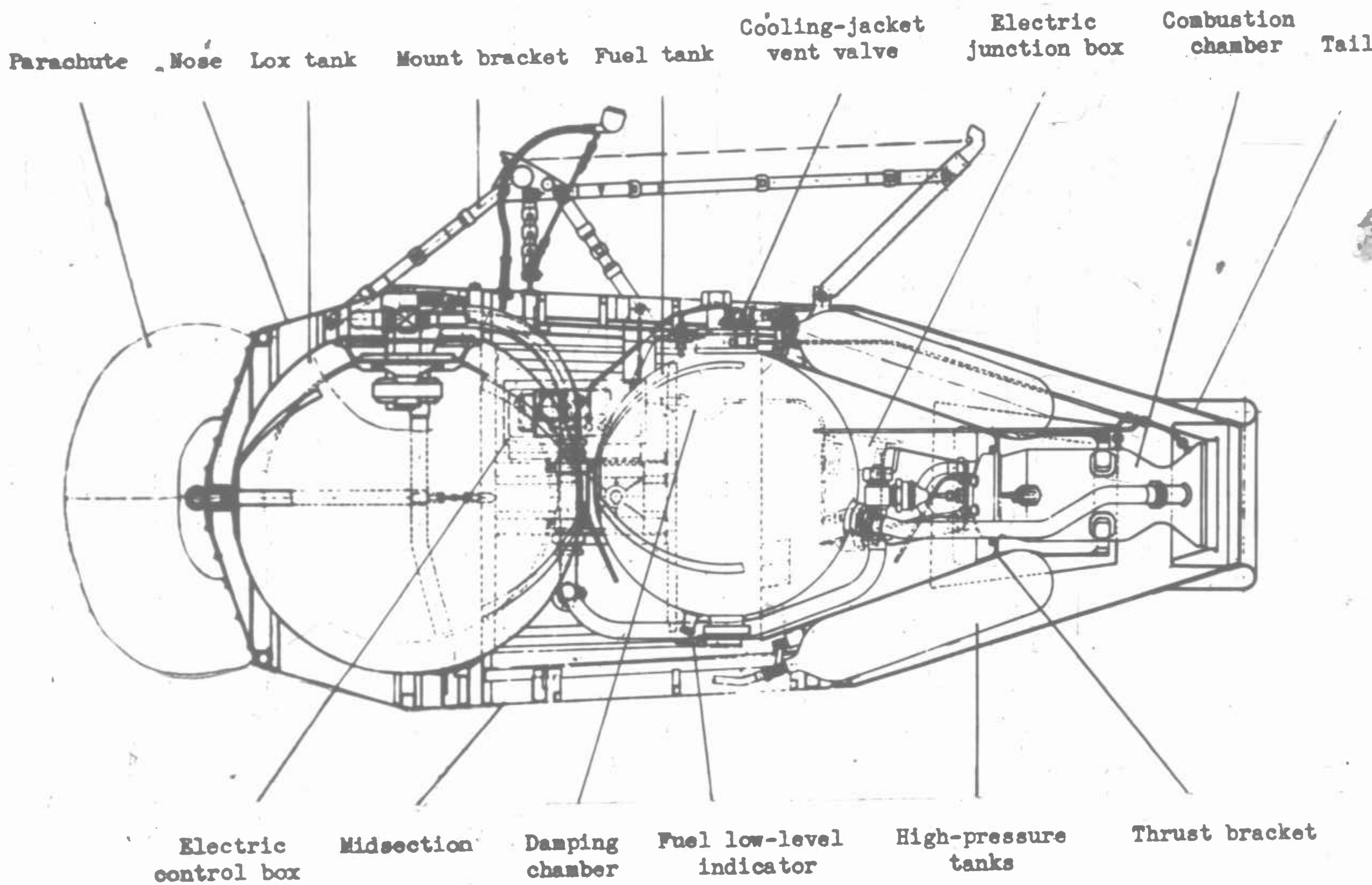
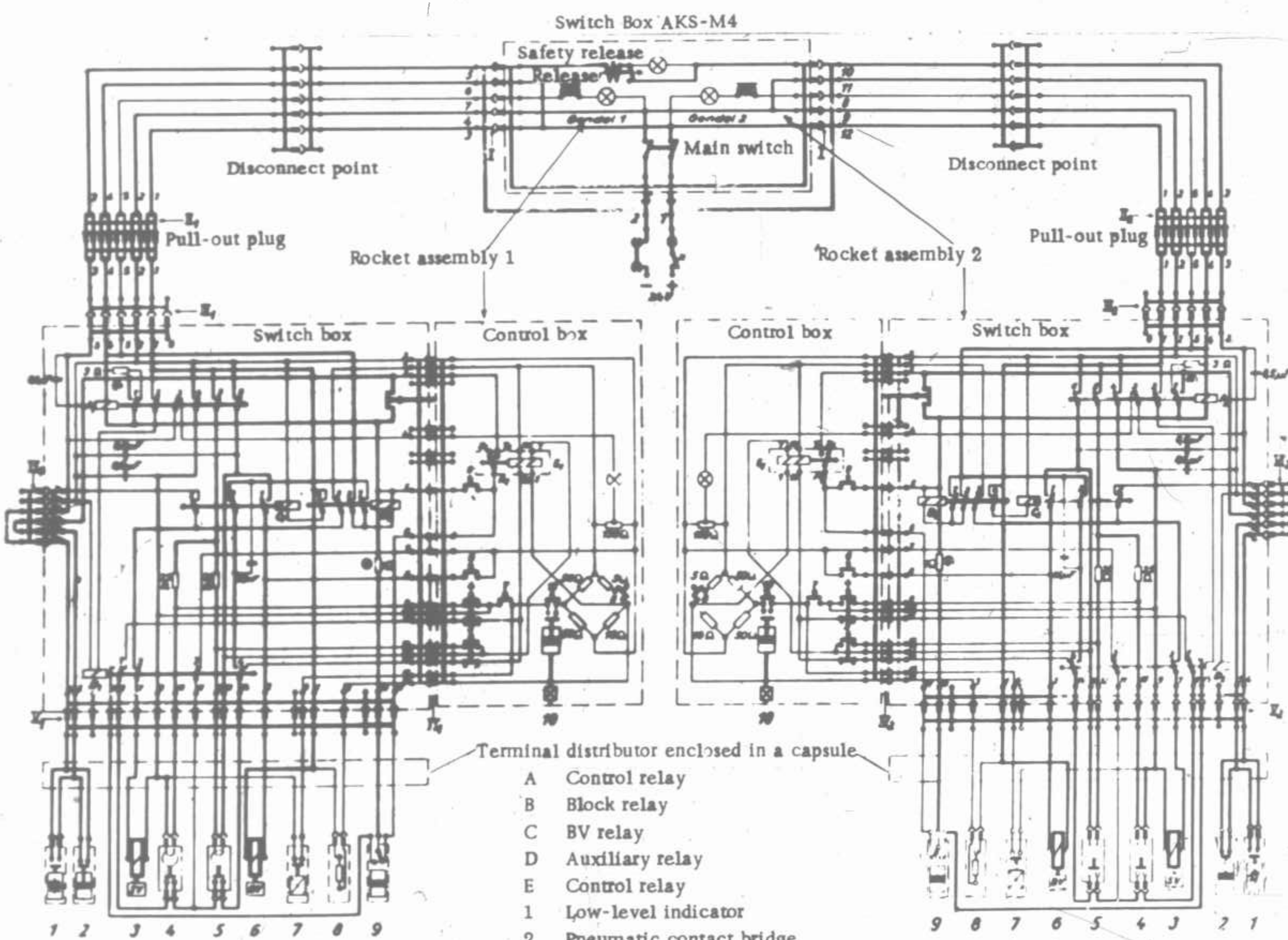


Fig. 7 - JATO RI-101B - Side View

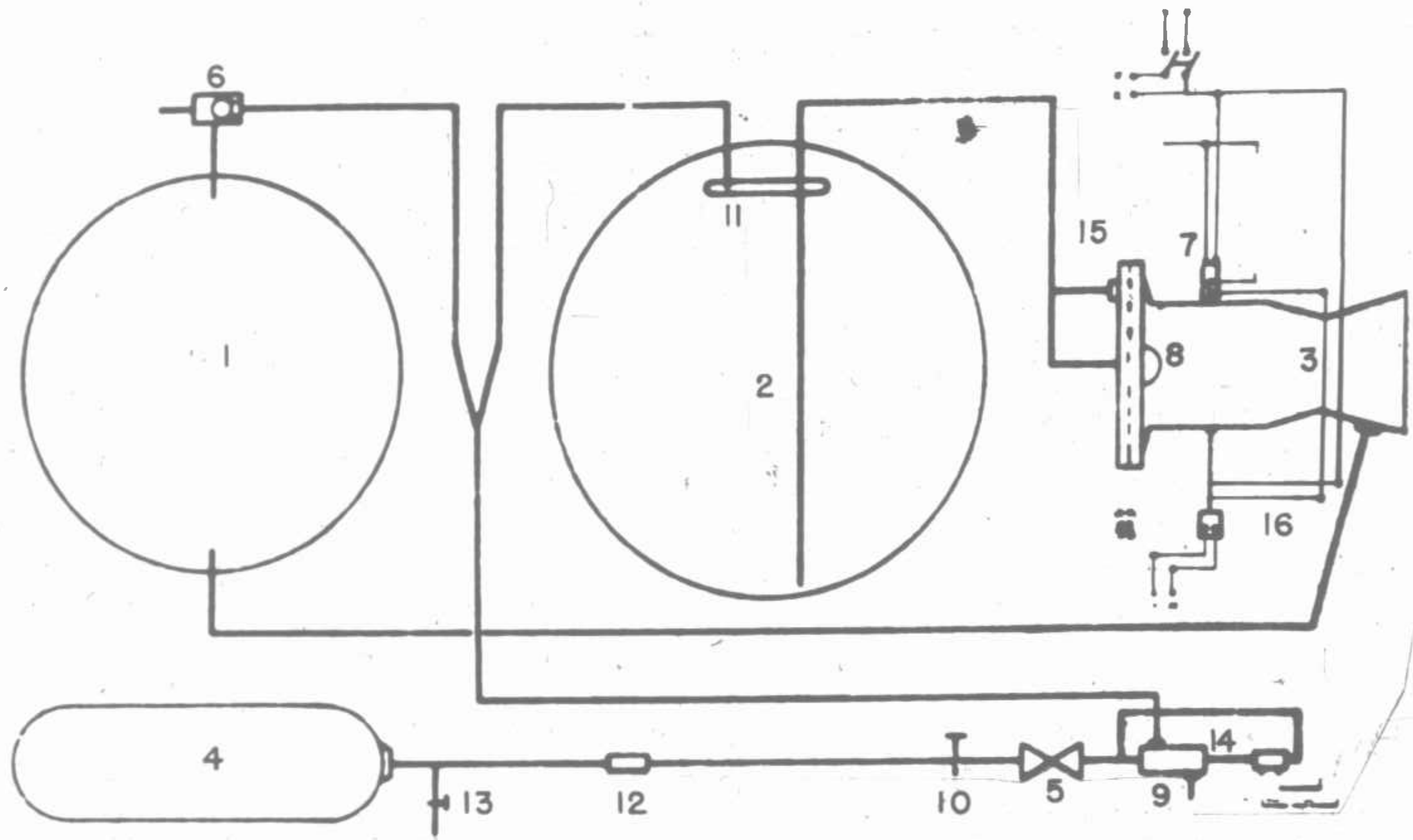


3	Liquid-oxygen valve	5	Igniter 2	7	High-pressure valve	9	Liquid-oxygen pressure switch
4	Igniter 1	6	Fuel valve	8	Fuel-tank indicator switch	10	High-pressure contact manometer

a In series production as resistance winding on A-relay

b Not used in series production [impulse winding = resistance winding (1Ω)]

Fig. 8 - Wiring Diagram - B-8a



1. Alcohol tank
2. Liquid-oxygen tank
3. Combustion chamber
4. High-pressure nitrogen tanks
5. Pressure regulator
6. Ball-check valve
7. Igniter
8. Liquid-oxygen injector with check valve
9. Pneumatically operated on-off valve
10. High-pressure hand on-off valve
11. Deflector plate
12. Filter
13. High-pressure fill valve
14. Solenoid pilot valve (Klauber-Simon)
15. Fuel cutoff valve
16. Pressure switch

Fig. 9 - Control Schematic - G-1

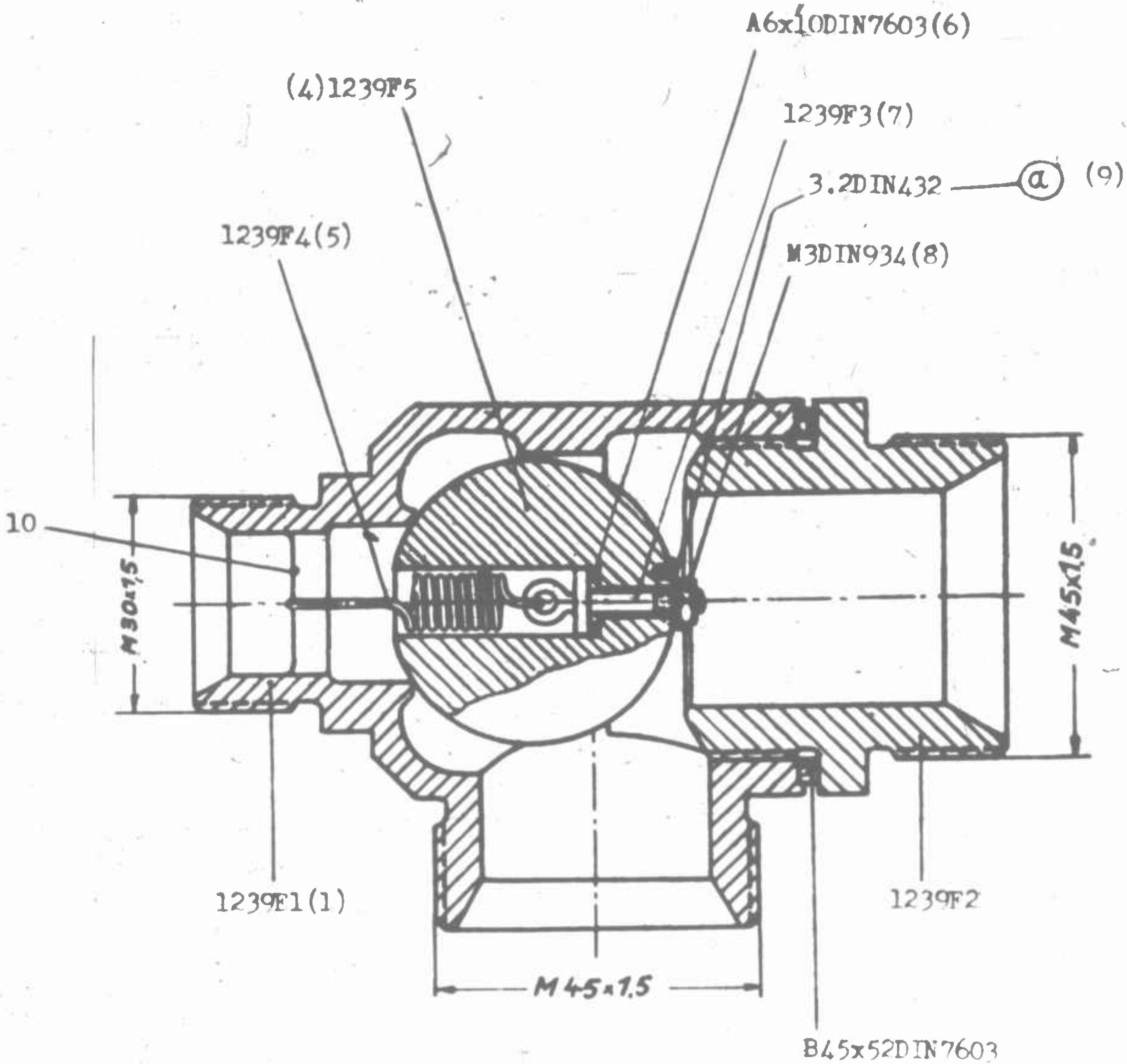


Fig. 11 - Ball Check Valve

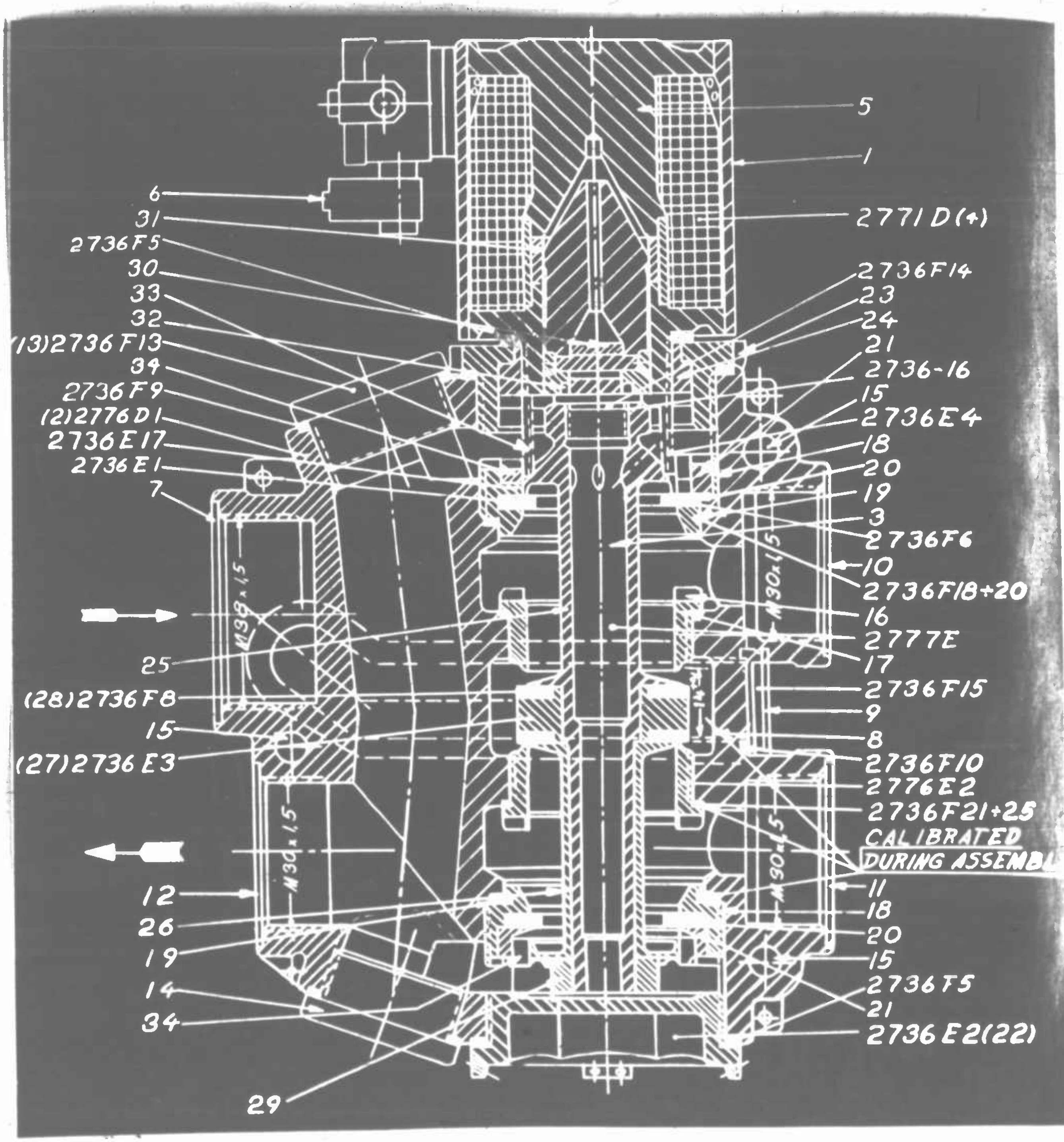


Fig. 12 - Solenoid 4-Way Valve

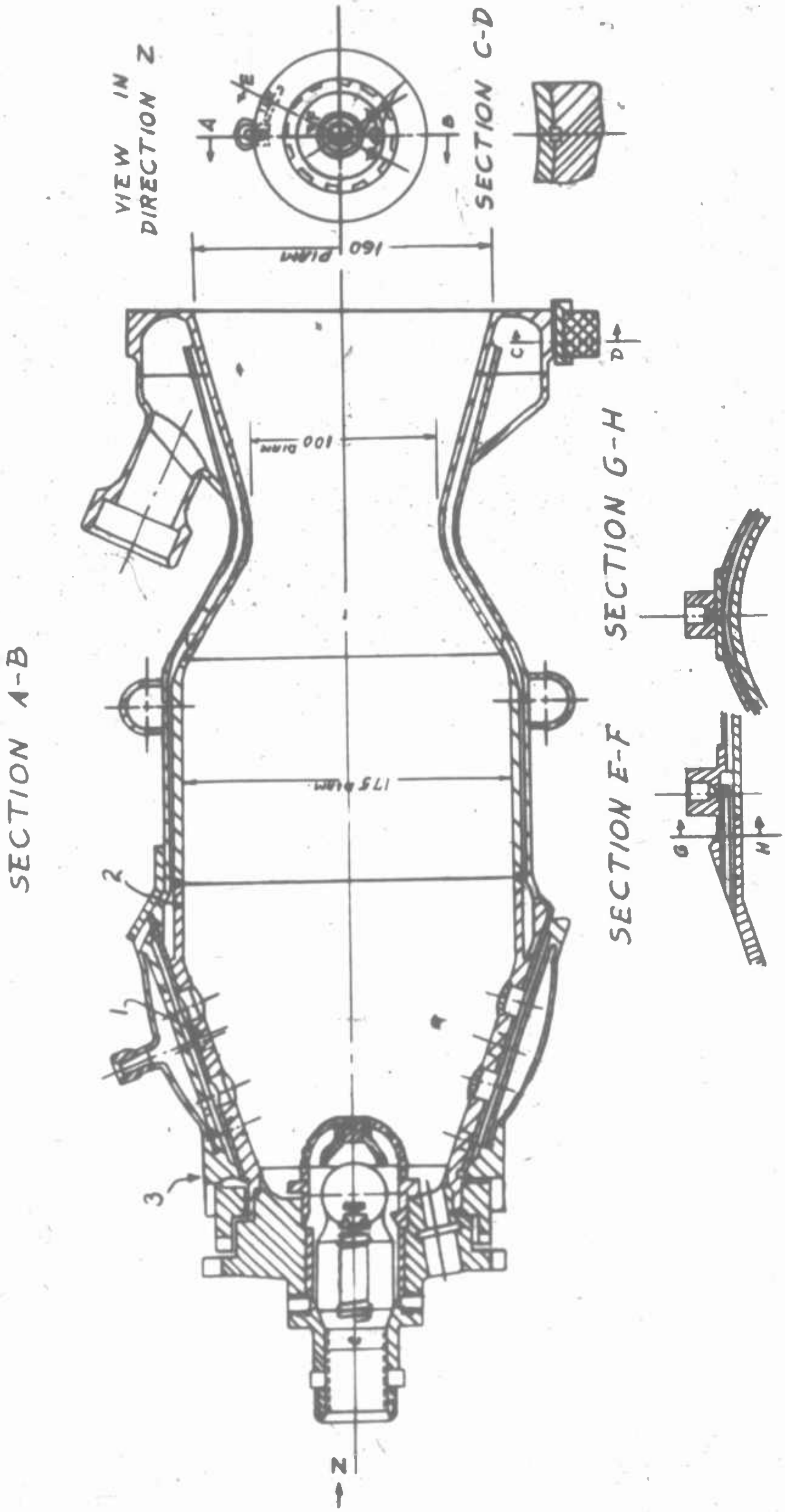


Fig. 13 - Combustion Cutoff Valve

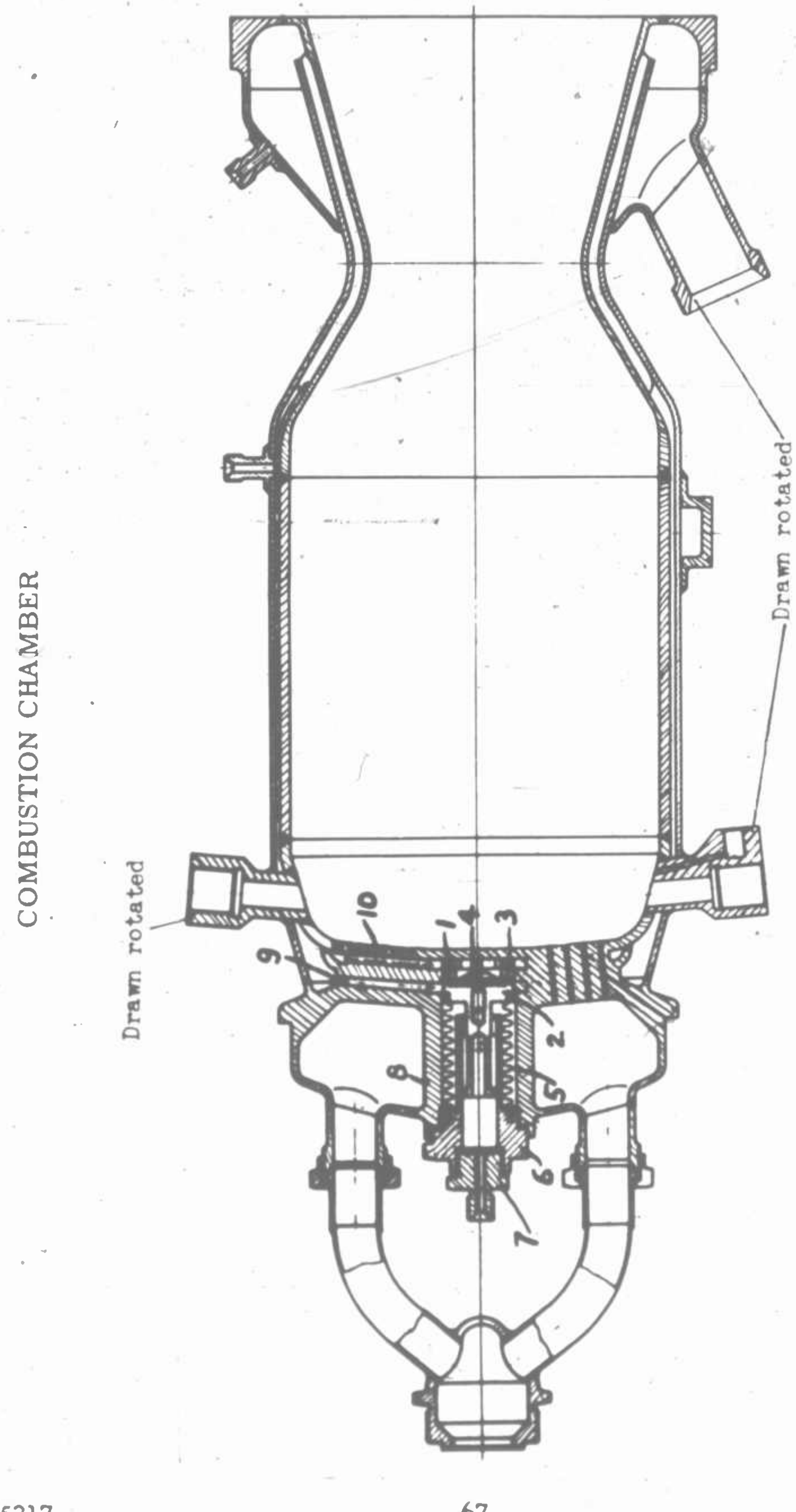


Fig. 14 - Combustion Cutoff Valve

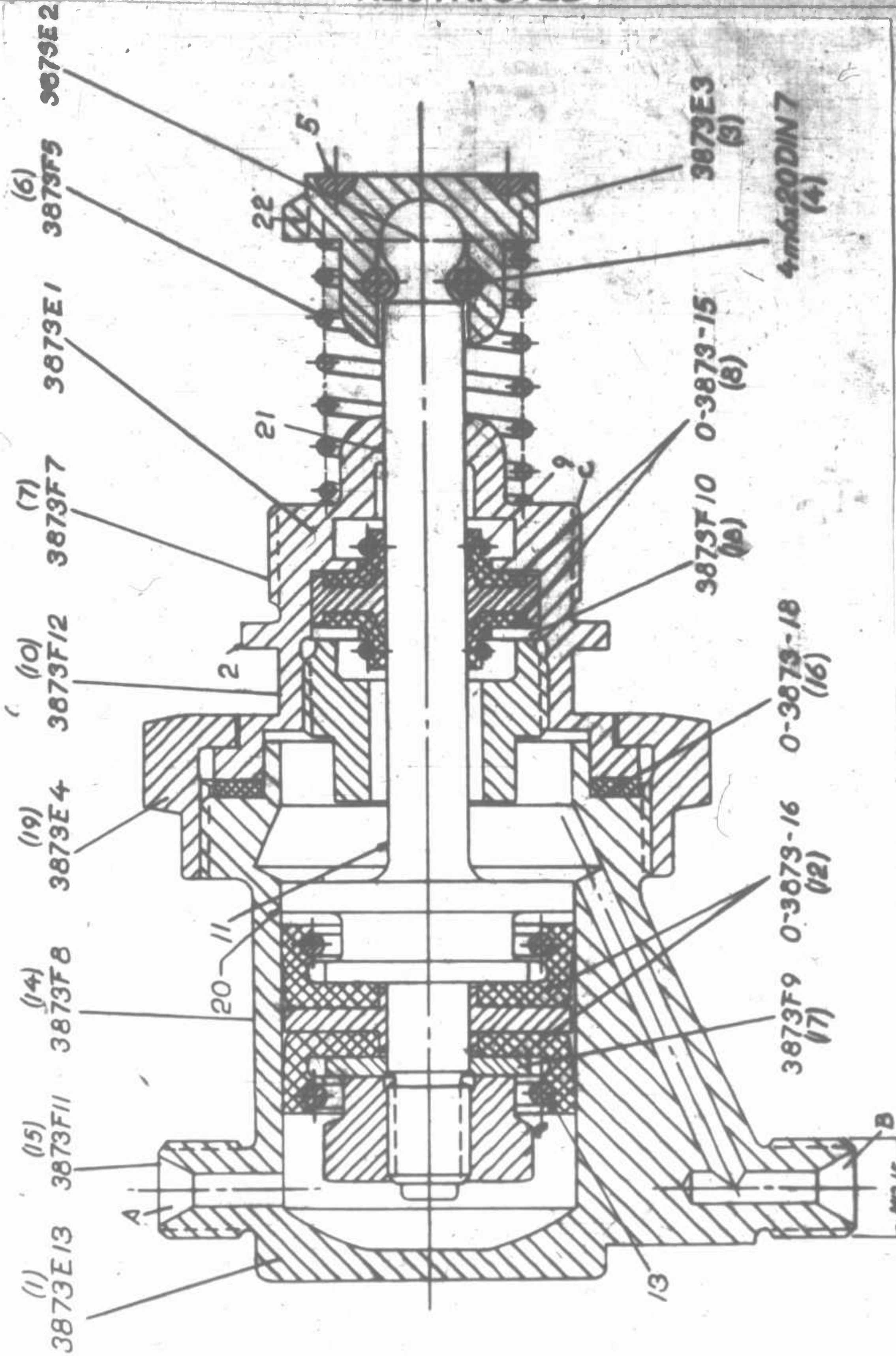


Fig. 15 - Combustion Cutoff Valve

ATI-85217

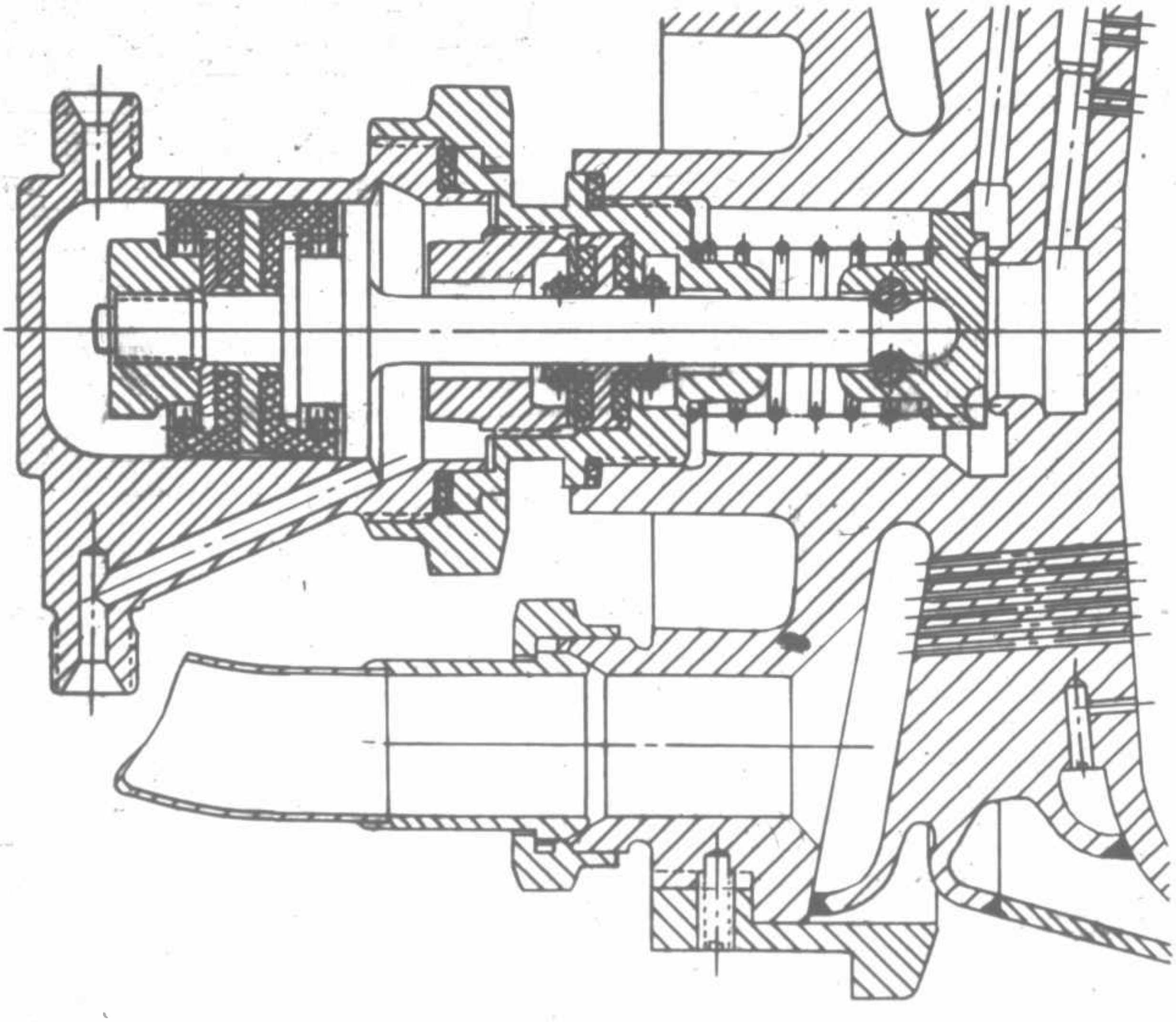
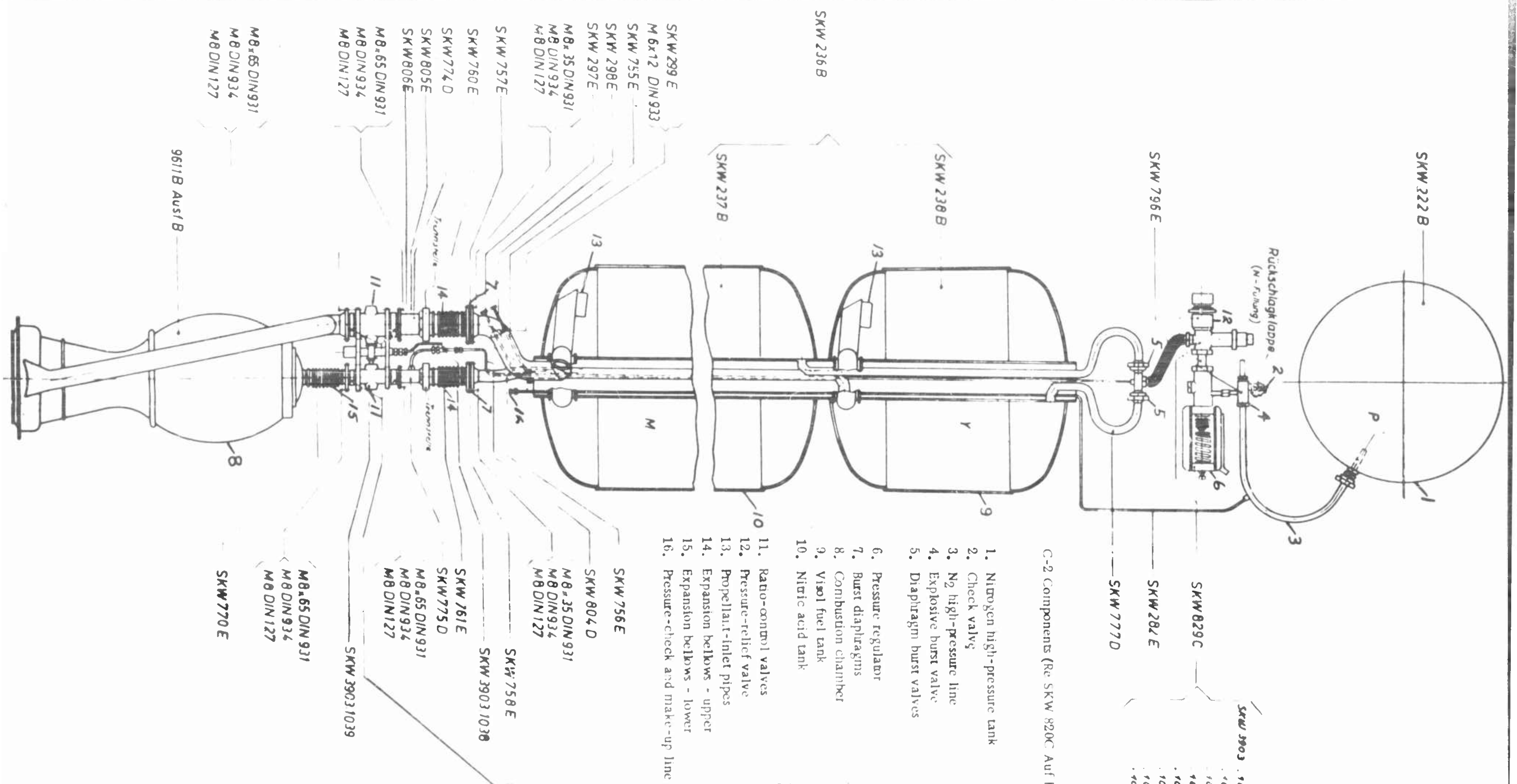


Fig. 16 - Assembly of Combustion Cutoff Valve



C-2 Components (Re SKW 820C Auf B)

1. Nitrogen high-pressure tank
2. Check valve
3. N_2 high-pressure line
4. Explosive burst valve
5. Diaphragm burst valves
6. Pressure regulator
7. Burst diaphragms
8. Combustion chamber
9. Visol fuel tank
10. Nitric acid tank
11. Ratio-control valves
12. Pressure-relief valve
13. Propellant-inlet pipes
14. Expansion bellows - upper
15. Expansion bellows - lower
16. Pressure-check and make-up line

Einbau der Düsen, Blenden und Distanzringe

		Schußgerät		Funktionsversuch		erster Spritzversuch		zweiter Spritz- oder Brennversuch	
	NW 70	Distanzring	SKW 614 F	Distanzring	SKW 614 F	Distanzring	SKW 614 F	Distanzring	SKW 614 F
	NW 70	Distanzring	SKW 614 F	Düse	SKW 798 E	[illegible]	SKW 620 E	[illegible]	SKW 620 E
	NW 40	Blende	SKW 781 E	Distanzring	SKW 615 F	Distanzring	SKW 615 F	[illegible]	SKW 780 E
	NW 40	Distanzring	SKW 615 F	Düse	SKW 799 E	[illegible]	SKW 621 E	[illegible]	SKW 621 E

Fig. 17 — Schematic Control Diagram - C2

71-72

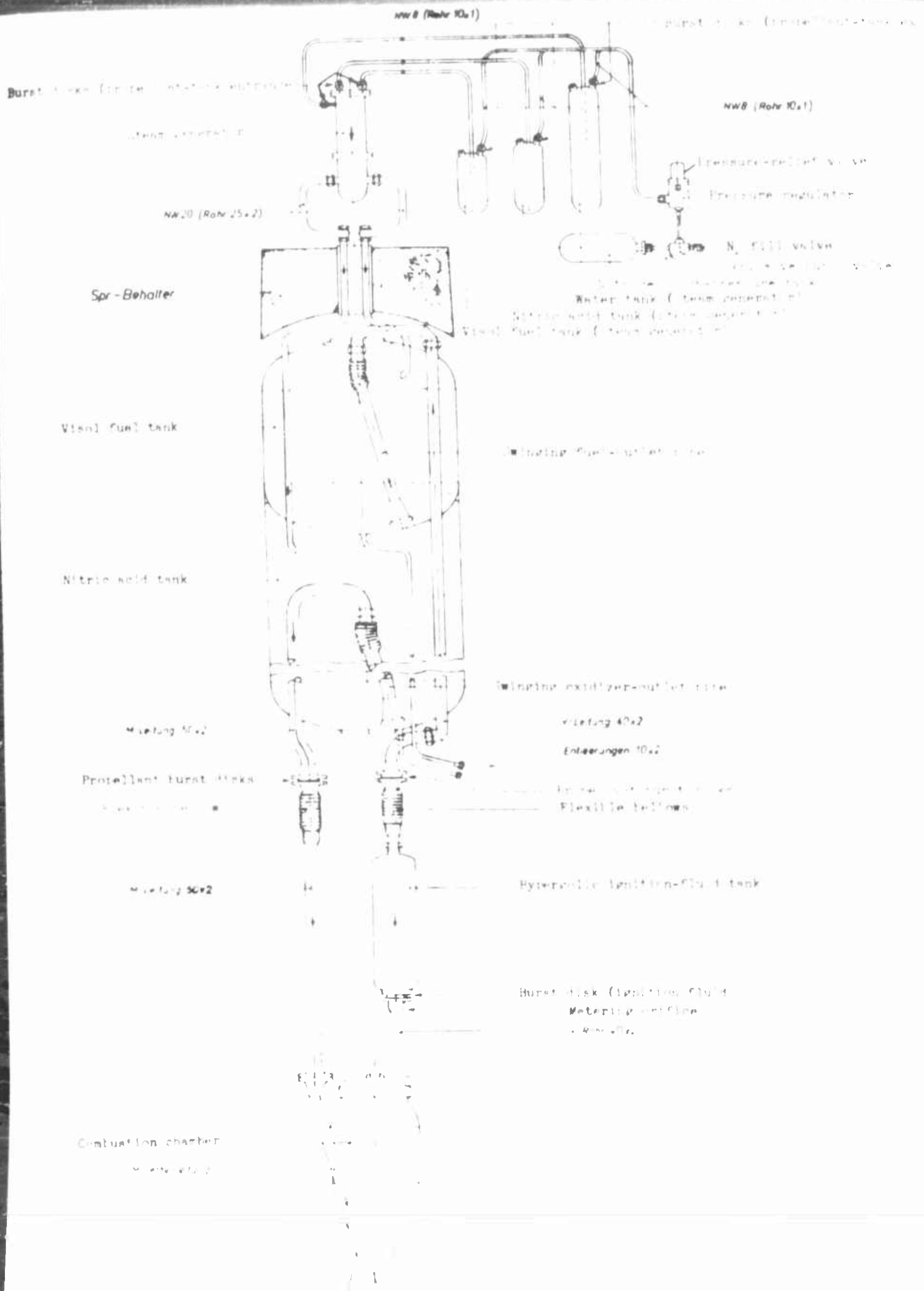
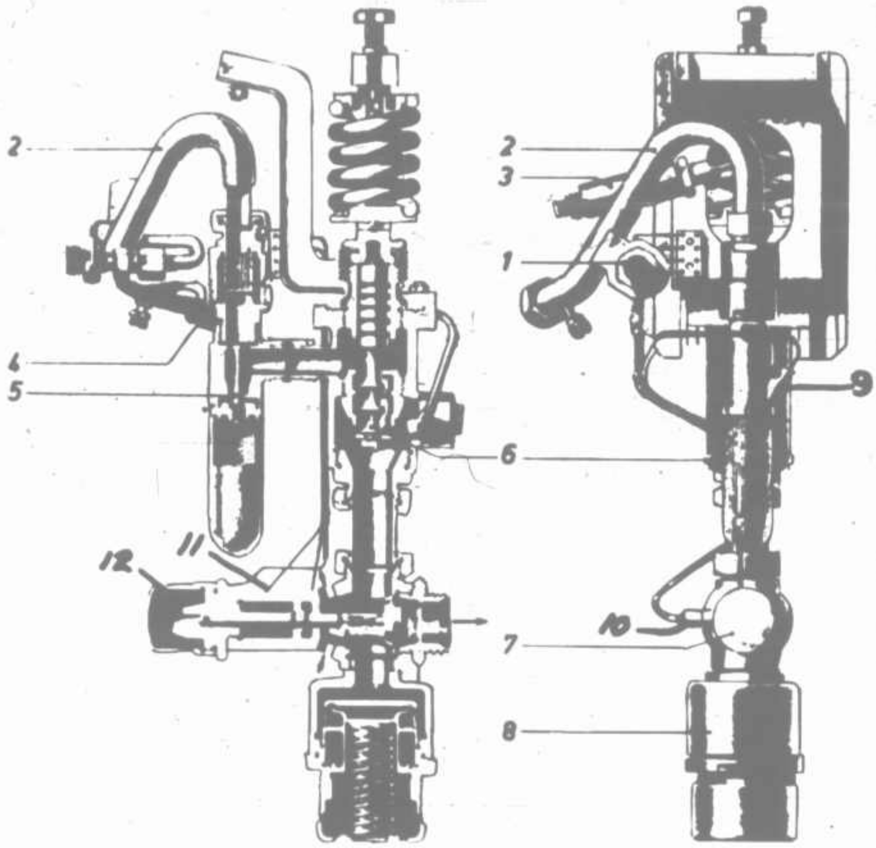


Fig. 18 - Schematic Control Diagram - C2



1. Nitrogen fill connection
2. High-pressure feed line
3. High-pressure relief valve
4. Strainer
5. Powder-cartridge burst valve
6. Pressure regulator
7. Vent valve
8. Surge damper
9. 10 and 11. Powder cartridge
12. Contact switch

Fig. 19 - Nitrogen Regulator Assembly

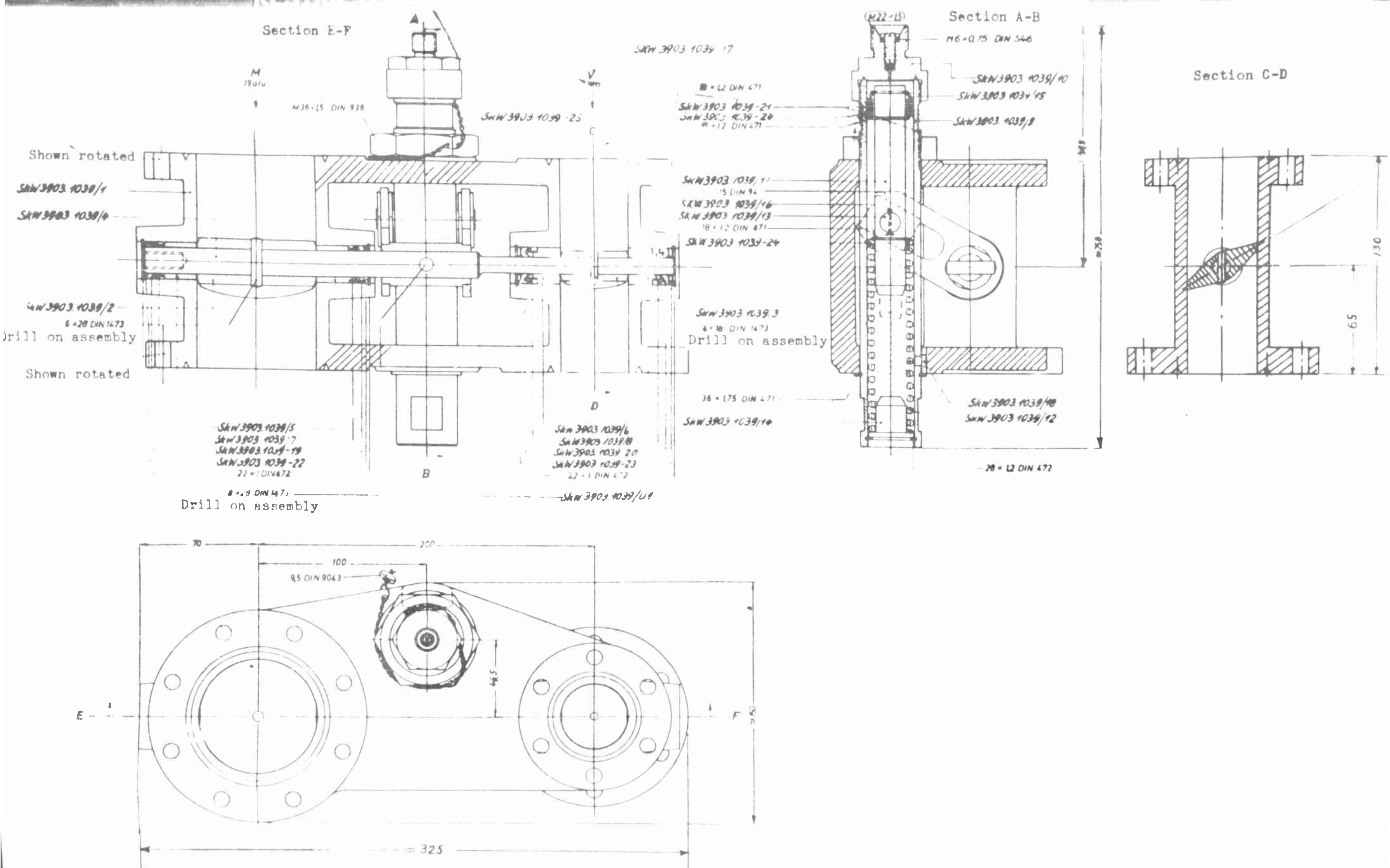


Fig. 20 - Propellant Control Valve Assembly

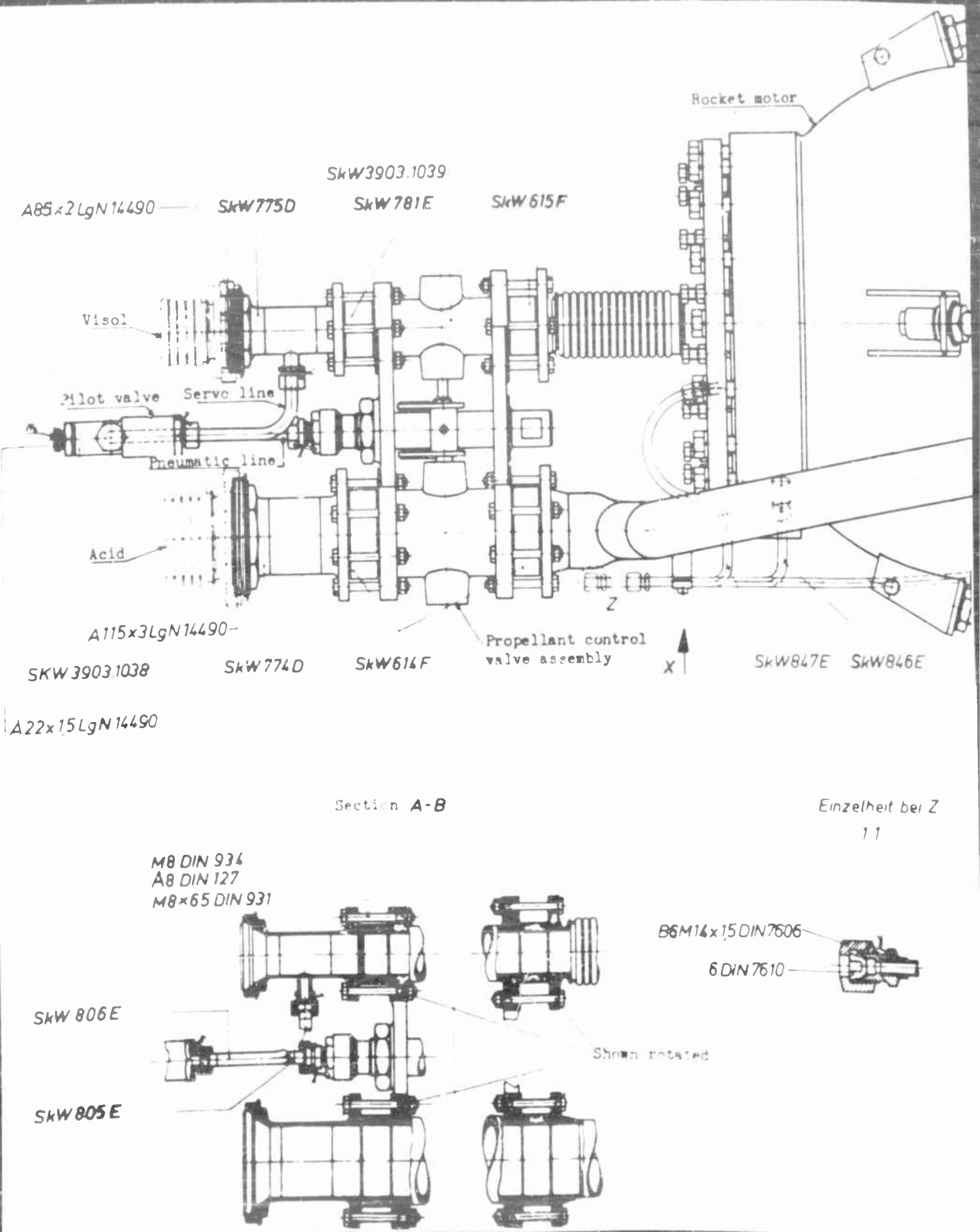
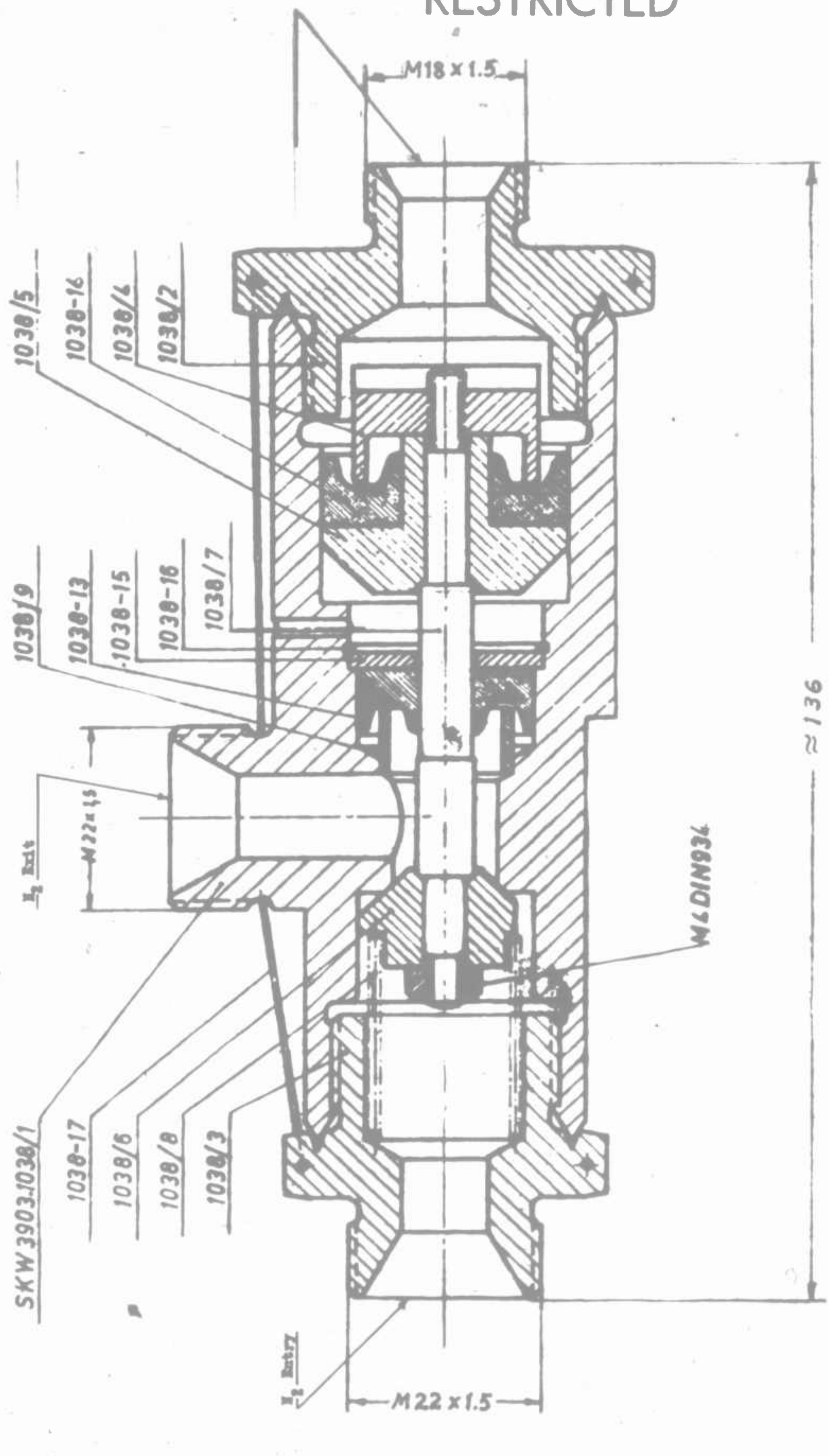


Fig. 21 - Propellant Control Valve Installation Assembly



Opening valve for N_2 selector

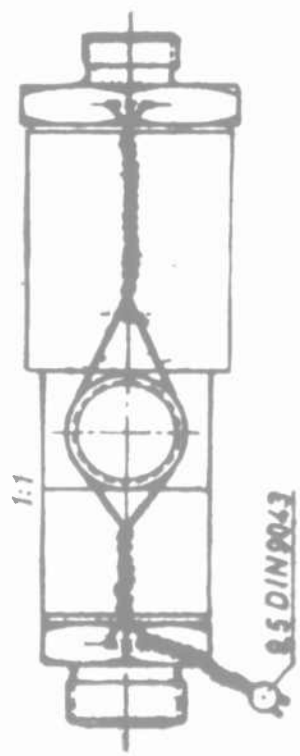


Fig. 22 - Pneumatic Pilot Valve

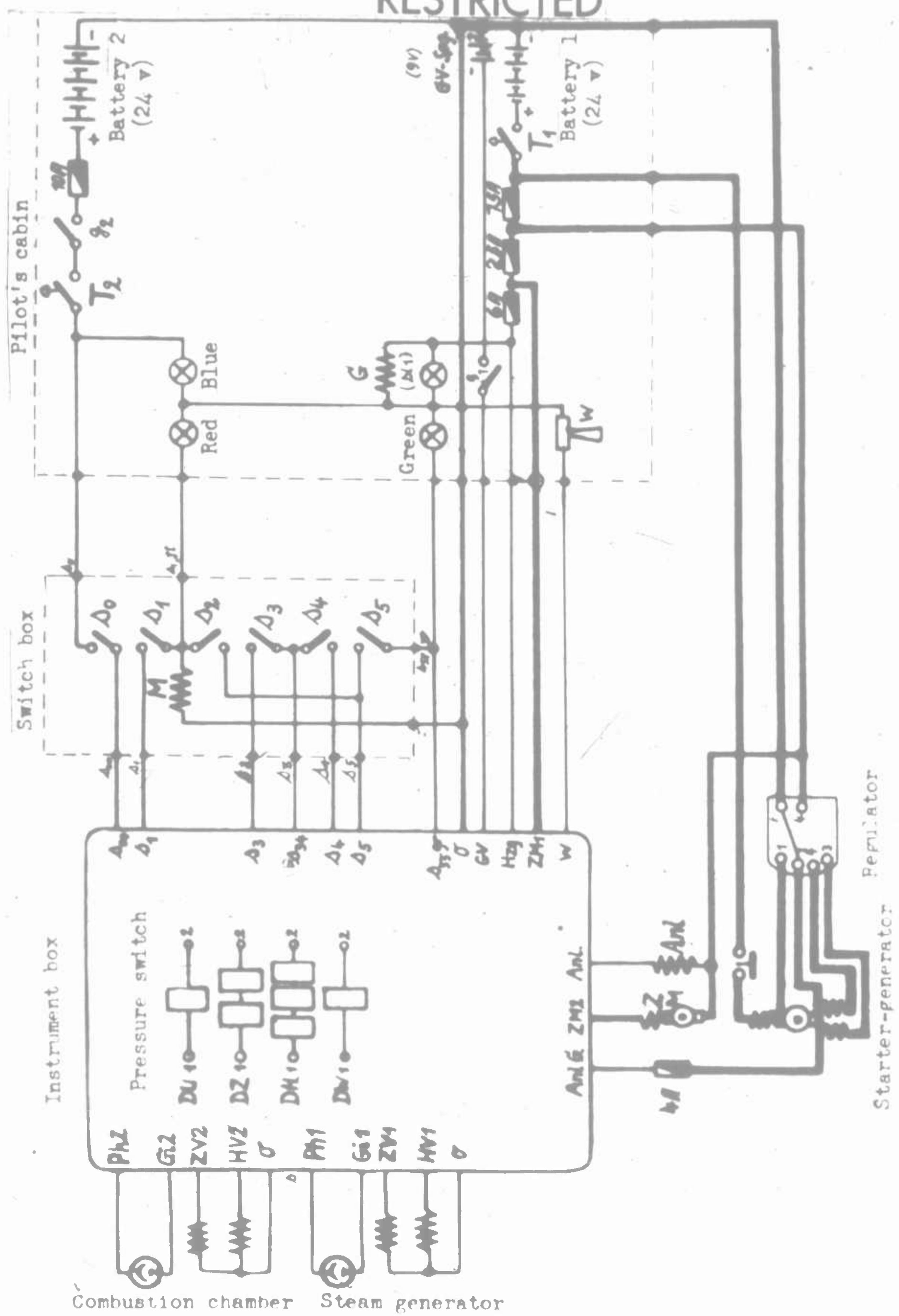
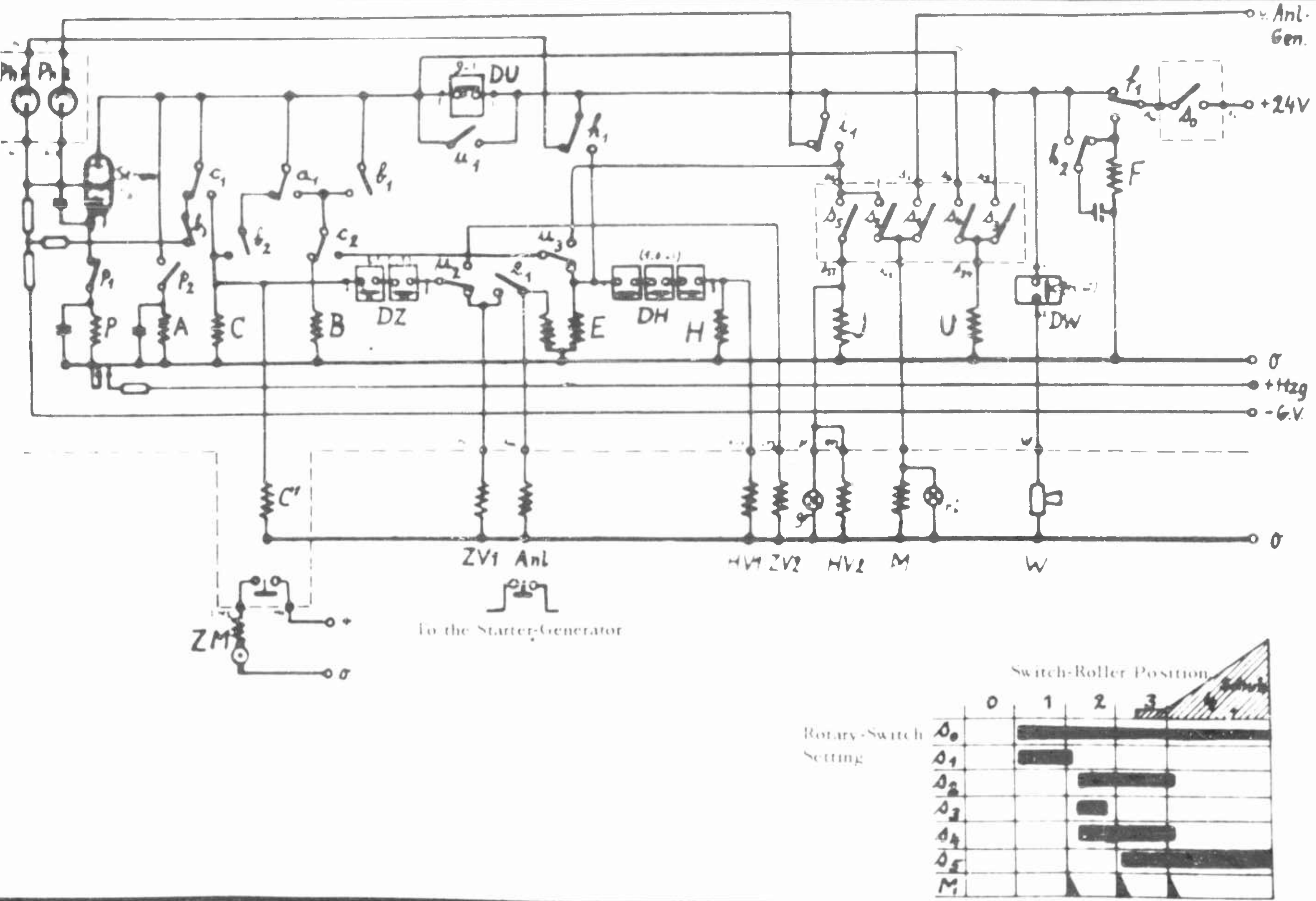


Fig. 25 - Component Interconnecting Wiring Diagram



Stromtor	Thyratron
v. anl. gen	From Starter Generator
Hzg	Heating
Anl	Starter
Schub	Thrust
Ph 1	Photocell - Steam Generator
Ph 2	Photocell - Combustion Chamber
DU	Pressure Switch - Steam (128 psi Opening)
DZ	Pressure Switch - Ignition Propellant (21 psi Closing)
DH	Pressure Switch - Main Propellants (14 psi Closing)
DW	Pressure Switch - Overspeed (568 psi Closing)
ZM	Ignition-Propellant Motor
ZV1	Ignition Valve - Steam Generator
HV1	Triple Valve - Steam Generator
ZV2	Ignition Valve - Combustion Chamber
HV2	Double Valve - Combustion Chamber
M	Blocking Solenoid
rt	Red Warning Light
W	Warning Horn
-GV	Grid Voltage (-)

Fig. 86 - Basic Wiring Diagram - P 3390A

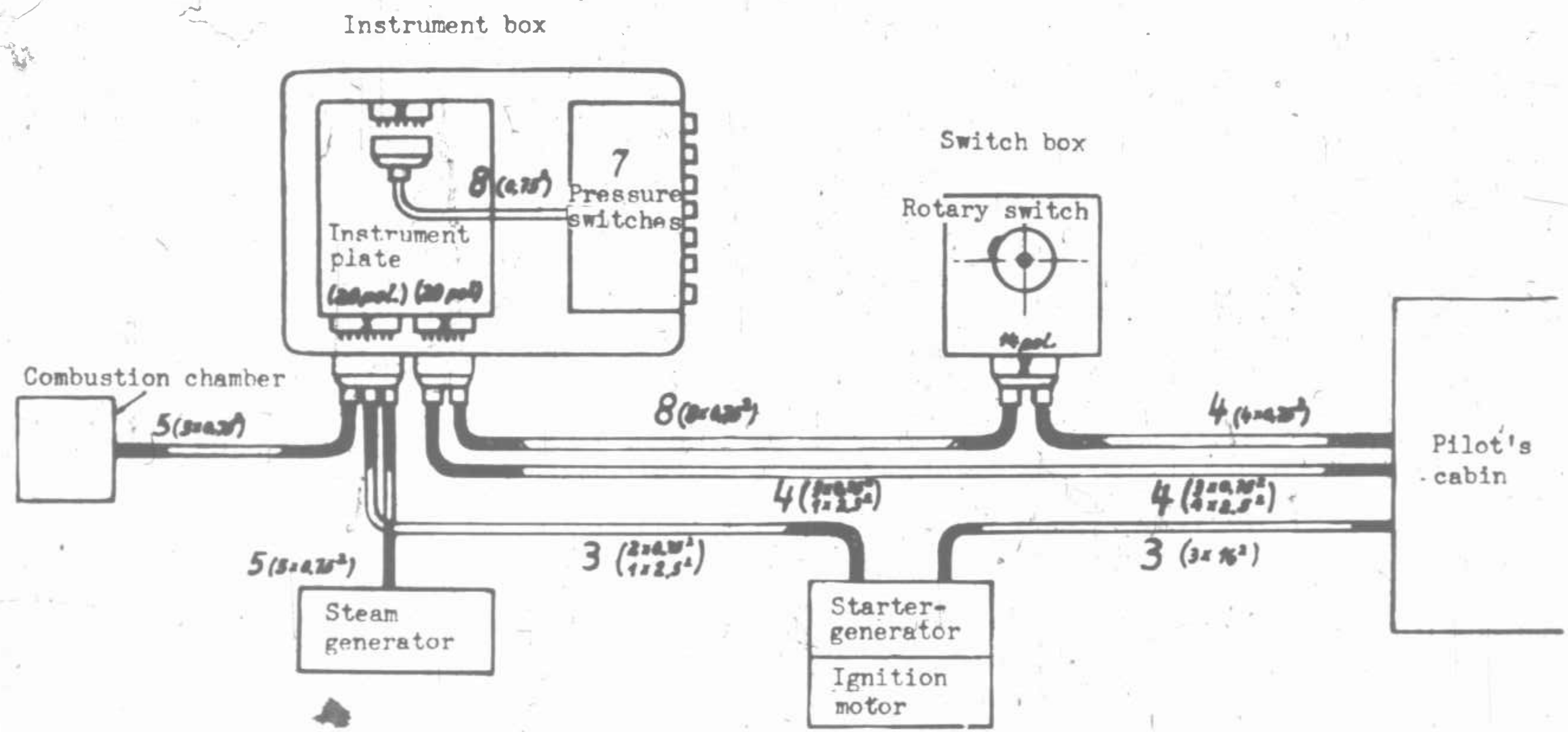


Fig. 27 - Installation Diagram - P 3390A Electrical Control

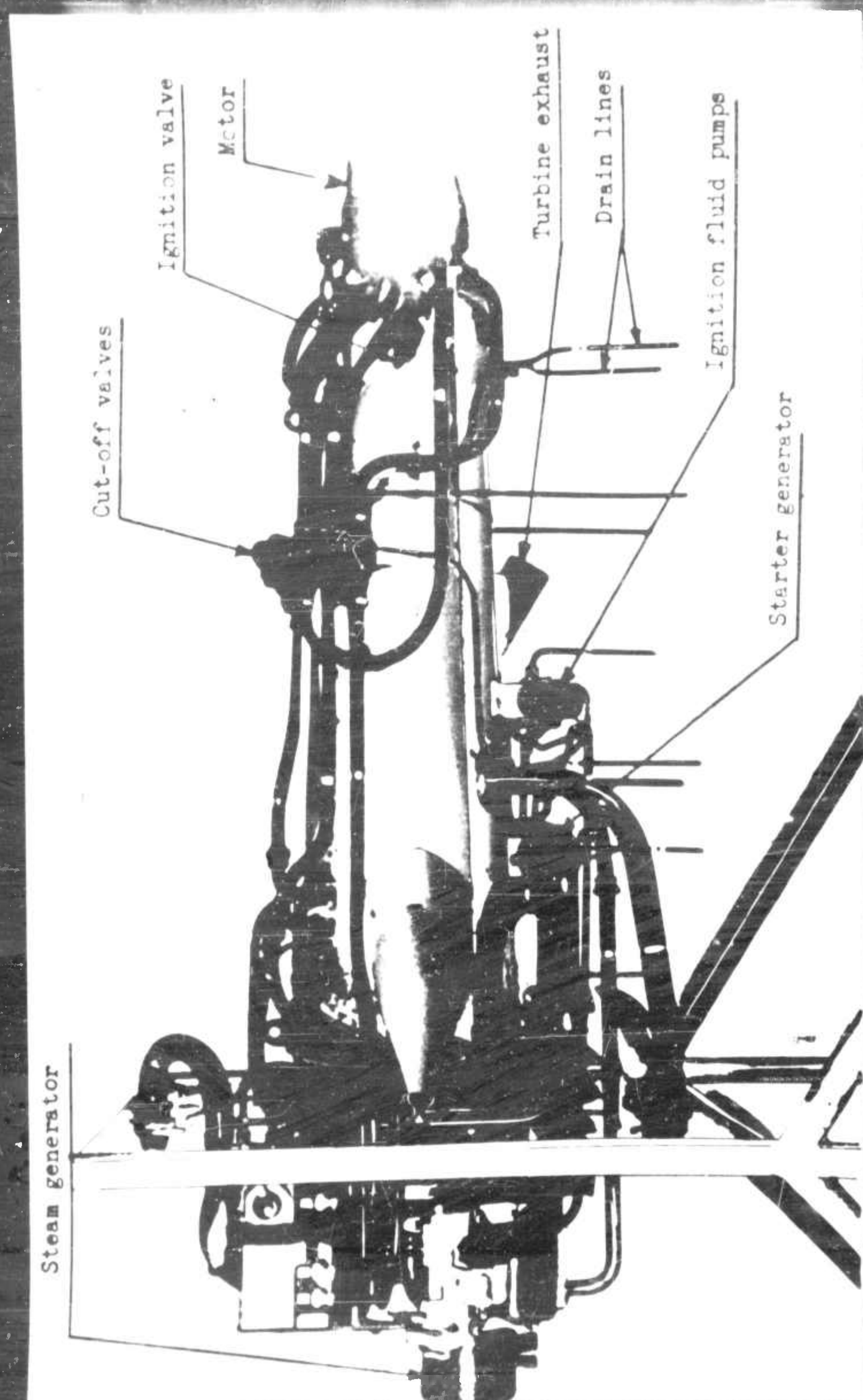


Fig. 28 - Outboard Profile - P 3390A

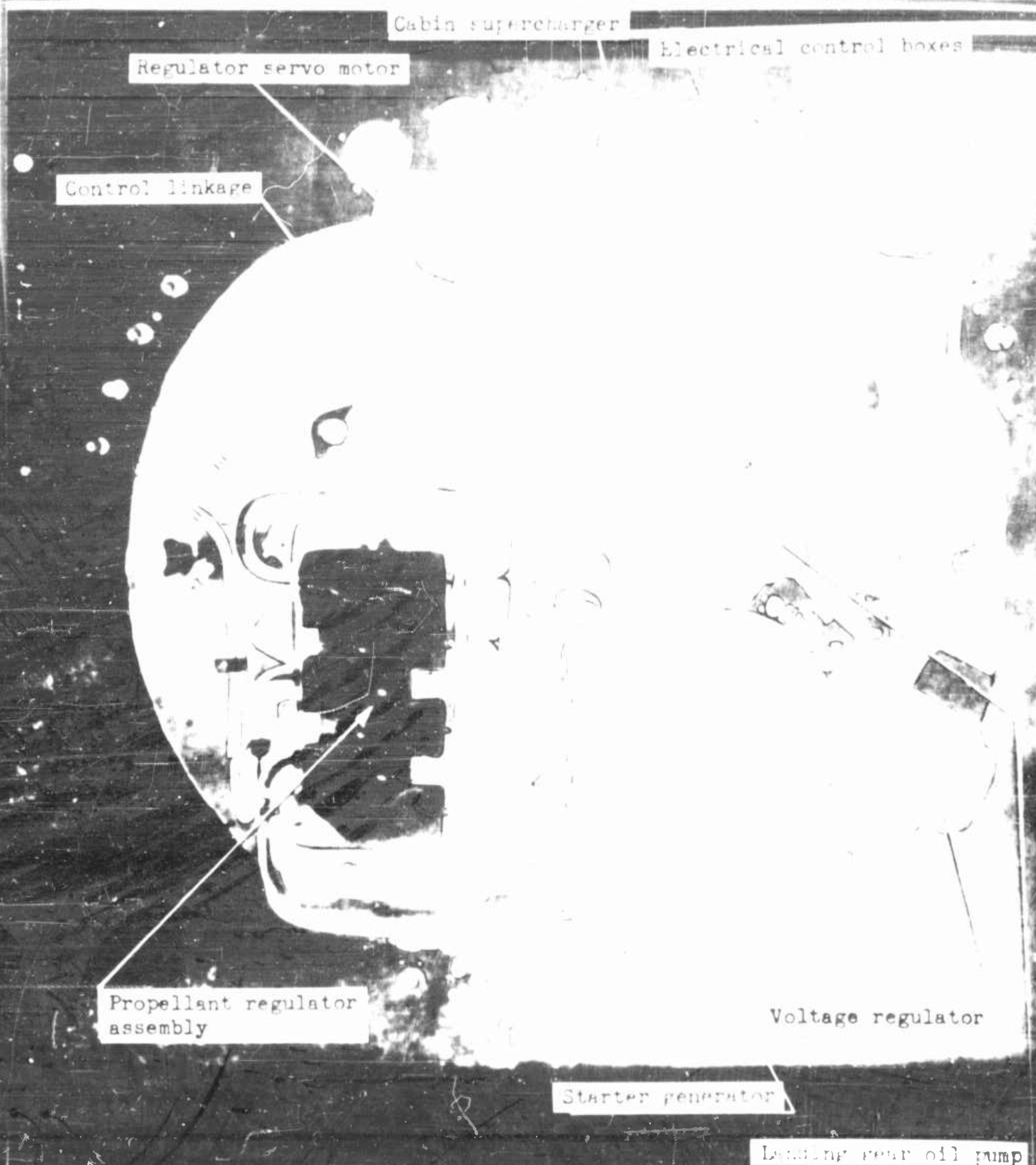


Fig. 29 - Front View - P 3390A
(Best available copy)

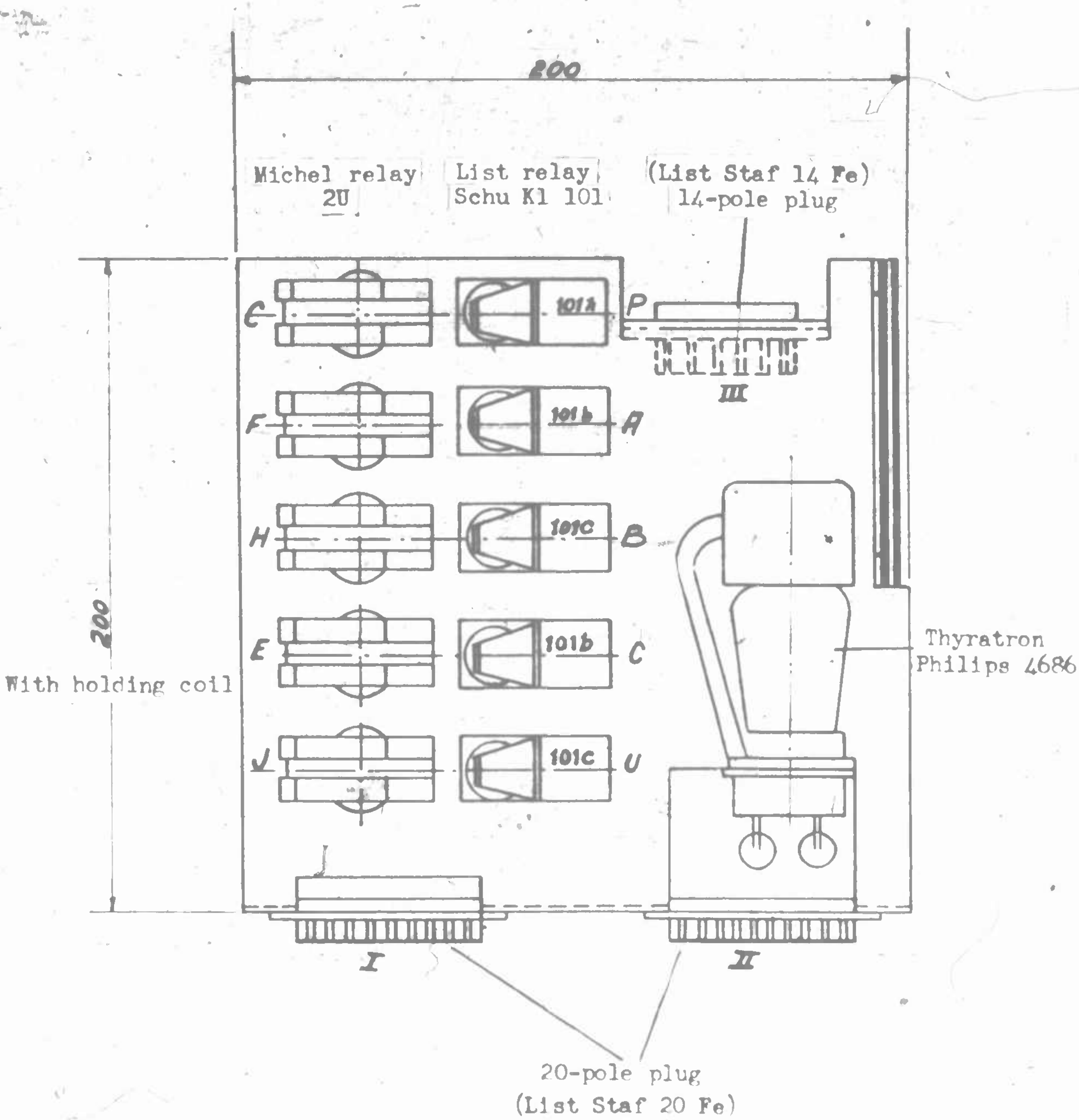
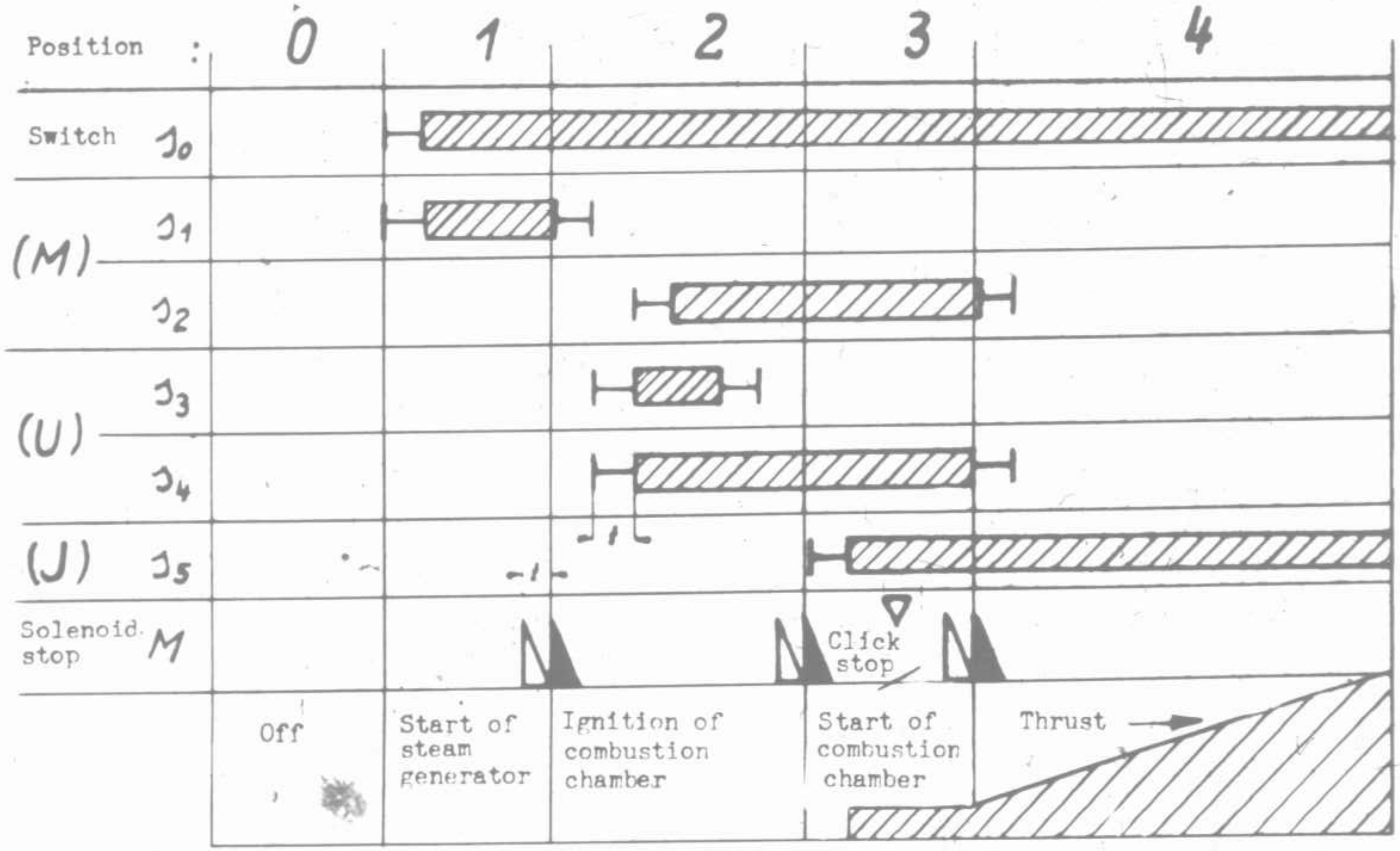


Fig. 30 - Instrument Box Installation



t = Tolerance width

Fig. 31 - Tolerance Chart - Rotary Switch Contacts

CLASSIFICATION CHANGED

ATI

FROM RESTRICTED TO UNCLASSIFIED
Insert Class Insert Class

85217

ON 27 Feb.1956 By authority of Classification cancelled in accordance with Executive Order 10501 issued 5 November 1953 Document Service Center Armed Services Tech. Info Agency
Month Day Year Specify Authority Being Used

This action was rendered by Arthur E. Creech OSP
Name in full Date

Document Service Center, ASTIA

EO 1CEC1 ac 5 NOV 190

~~RESTRICTED~~ (CORR. COPY 1)

025 900

ATI 85 217

(COPIES OBTAINABLE FROM CADO)

AMERICAN POWER JET CO., MONTCLAIR, N.J.

ANALYSIS AND EVALUATION OF GERMAN ATTAINMENTS AND RESEARCH IN THE LIQUID ROCKET ENGINE FIELD - VOL. VIII ROCKET ENGINE CONTROL AND SAFETY CIRCUITS

FEB '51 108PP. PHOTOS, DIAGRS

AMC, WIRHT-PATTERSON AIR FORCE BASE, DAYTON, O., USAF CONTR. NO. W33-038-AC-17485 AND AF33(038)3636 (F-TR-2251-IA)

GUIDED MISSILES ~~(1)~~ (4) ENGINES, ROCKET - GERMANY (12)
PROPULSION (3) ENGINES, ROCKET - CONTROL SYSTEM

CFSTI, auth: ETD ltr, 12 Sep 68

~~RESTRICTED~~

AD-A800 120

CADO FORM 5C (REV 1 DEC 50) AIR FORCE-WPAFB.L-18 DEC 50 210M

DISTRIBUTION:

ATI:

TITLE: No corr. to be run. Perm. card is OK

FOREIGN TITLE: Information was taken from [illegible]

AUTHOR(S): All 5x8 were corrected

ORIGINATING AGENCY: U auth: DF fr Air Technical

O.A. NO.:

PUBLISHING AGENCY: Intelligence Center dd 1 Sept 54

P.A. NO.:

TRANSLATING AGENCY: (21 Sept 54)

T.A. NO.:

DATE:	COUNTRY:	LANGUAGE:	PAGES:	REMARKS:

SUBJECT	
DIV.	SECT.

SUBJECT HEADINGS: P21/8.1 LIQUID PROPELLANT ROCKET ENGINES